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US Army Corps of Engineers®
Engineer Research and Development Center

Understanding Condition Indexes

Current Status and Future Opportunities

Stuart D. Foltz, Paul A. Howdyshell, and David T. McKay

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Foreword

This study was conducted for Operations Division, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Military Interdepartmental Purchase Request W26HM490496461, "Implementation Issues and Strategy for Condition Indexes and Quadrant" (Appendix A includes the scope of work for this project). The technical monitor was Harold Tohlen, CECW-O.

The work was performed by the Facilities Maintenance Branch (CF-F), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was David T. McKay. The technical editor was Linda L. Wheatley, Information Technology Laboratory — Champaign. Mark Slaughter is Chief, CF-F, and Michael Golish is Chief, CF. The associated Technical Director is Alan W. Moore, CV-T. The Acting Director of CERL is Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

A Condition Index (CI) is a snapshot look at the condition of a part or component of infrastructure. CIs for Civil Works infrastructure were developed at the direction of the Civil Works Directorate, Headquarters, U.S. Army Corps of Engineers (HQUSACE) as part of the Operations Management Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program. CIs were developed to assist in the prioritization of nonrecurring maintenance work packages in the annual operations and maintenance (O&M) budget and to assist in defending the budget. Funding of CI development began in the mid-1980s and ended in Fiscal Year (FY) 1998. Since the program began, there have been many changes in business practices within and outside the Corps of Engineers. Some of these changes affect the application, requirements, and benefits related to CIs. The CI product has also deviated from what was originally proposed, which is due to both changes in the business environment and a better understanding of what CIs can and cannot accomplish. It has been 11 years since a formal document was produced to outline the roles or potential roles for CIs.

The O&M Management Tools program, scheduled for funding in FY00-02, is an opportunity to revisit and rework the CIs to assure that they both meet their original and modified design intent and are sufficiently user friendly to assure technology transfer and utilization. Appendix B is the Congressional Justification sheet for the FY00 O&M Management Tools program, and Appendix C is the detailed proposal from which the program evolved. Funding related to CIs is also being obtained through an electrical/mechanical spillway gate work unit in the "Risk Analysis for Dam Safety" research program. A copy of the RDMIS (work statement) is included in Appendix D.

Thus far use of CIs by Civil Works (CW) Districts has been limited, even though the annual Engineer Circular (EC) on the Civil Works Direct Program, Program Development Guidance, states that CIs are a required part of the proposed work package submittal for work packages in specific category codes. A 1997 telephone survey of CW Districts conducted by the Construction Engineering Research Laboratory (CERL) confirmed the low utilization of CIs (see Chapter 6, p 45). To assure better utilization of the updated CIs, the current business prac-

tices at Districts, Divisions, and Headquarters relative to CI utilization need to be understood. Understanding why the CIs have not been generally used and why and how they are used is essential so that the CIs can be presented, modified, simplified, or expanded to better meet the real need. The relationship between CIs and other CW business processes also needs to be determined for the CW environment of today and tomorrow. Examples of business processes that include or could include CIs are O&M work package prioritization in the Automated Budgeting System (ABS), input to a cost/benefit analysis tool (Quadrant), and input to major rehabilitation reliability analysis. In addition, the CI inspection requirements need to be integrated and coordinated with other inspection requirements to control cost and optimize benefits.

Objectives

The objectives were to (1) study implementation of CIs within USACE, (2) investigate roles that CIs could support or fulfill, and (3) report the current and potential benefits of CIs. Although this report is broader than just the O&M Management Tools program, the results of this work will focus the work within that program to assure that the final CI products both meet the original and modified design intent and are sufficiently user friendly to assure technology transfer and utilization. It is expected that this will be a living document that is updated periodically throughout and beyond the O&M Management Tools research program.

To this date, CIs have primarily been used within Districts as an additional inspection tool and to quantify baseline conditions for future reference. This report discusses many other potential uses of CIs. It is uncertain which uses are feasible and which meet the more difficult requirement of being cost effective. It is hoped that developing more of the potential uses can maximize the cost effectiveness. Regardless of these considerations, the long-term objective is to determine when, where, and how CIs can be used effectively.

Approach

The approach used to achieve the above objectives included the following:

- A general description of CIs including potential benefits, current utilization, common perceptions, and implementation policy
- The relationship between CIs and work packages within ABS
- CIs as input to reliability and risk analysis
- CIs as a component of an integrated inspection initiative

- CI technology transfer requirements
- Future research objectives and products.

Scope

As with any working document, this report contains some incomplete information. One example is the section on CI simplification. Possibilities for simplifying some CIs have not yet been considered. Other areas, such as using CIs within reliability, will undergo changes as more knowledge is gained.

2 Condition Index Implementation

General Description of CIs

A CI is a quantitative rating between 0 and 100 that estimates the physical condition, as a snapshot in time, of a structure or structural component (Table 1). CIs were originally developed with the intent of using them to assist in prioritizing and justifying the nonrecurring packages in the O&M budget. The ratings are based primarily on physical deterioration as determined by distresses that can be seen or measured. Most indexes also include some consideration of safety and function. Although the indexes that have been developed vary somewhat, they generally include: (1) an inspection procedure (all CIs except embankment dams), (2) simple measurements and visual observations (all CIs) or slightly more involved measurements (gates), and (3) a quantification of condition (all CIs). The condition quantification is based on subcomponent weightings (all CIs except concrete and hydropower) and either quantities and measurements (gates, operating equipment, and concrete) or subcomponent condition descriptions (embankment dams, breakwaters and jetties, riverine rubble dikes). Unlike other CIs, the condition quantification for hydropower is based on the poorest indicator (series or weakest-link-in-the-chain analogy).

Table 1. U.S. Army Corps of Engineers REMR condition indexing scale.

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	**Excellent:** No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	**Good:** Only minor deterioration or defects are evident.	
2	55 to 69	**Fair:** Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	**Marginal:** Moderate deterioration. Function is still adequate.	
3	25 to 39	**Poor:** Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	**Very Poor:** Extensive deterioration. Barely functional.	
	0 to 9	**Failed:** No longer functions. General failure or complete failure of a major structural component.	

The figures in Appendix E show the status of all developed, under development, and undeveloped CIs in each primary business area. These figures indicate that CIs have been completed or are nearly complete for the major CW-unique critical components that make up the Navigation, Flood Damage Reduction, and Hydropower business areas. Notable exceptions include lift gates, levees, and standard commercial equipment (electrical motors, etc). CIs have not been developed for the Recreation or Environmental business area, but the engineered management systems (e.g., PAVER and Builder) developed for military installations could be applied to CW recreation facilities without significant modifications.

The development of CIs focused primarily on creating the inspection procedures necessary to collect the information needed for quantifying condition. Review of structural design and analysis of design adequacy were considered to be beyond the intended scope of CIs. The inspection procedures were to be objective measures targeted for completion by technicians and non-expert engineers. A criterion of the inspection procedures was that resulting CIs varied less than 10 points between various inspectors assessing a particular structure. Embankment Dam and Hydropower CIs are exceptions to the focus on developing new inspection procedures and CI criteria. It was felt that existing procedures and policies for embankment dams, though probably less standardized than intended for CI inspection procedures, resulted in adequate inspection information. The Hydropower CIs are based primarily on the wealth of existing test procedures and monitoring equipment required for the operation of hydropower equipment.

It should be apparent that not all CIs are created the same. In some ways this was a matter of evolution in development. Lessons learned in new work were not always implemented in previous CIs. In other cases, variations in the situation for a component limited the possibilities for creating a CI or presented different potential or desired benefits. In addition to the differences specifically mentioned in the last paragraph, some indexes are more objective than others. This difference was usually closely related to the inspection information available or the ability to collect it but also had some relationship to differences in business practices among engineering disciplines.

CIs – Current and Potential Benefits

After discussions with HQUSACE, field personnel, and other researchers, the CI research team believes that, in addition to using CIs to aid in work package prioritization, there are a number of other current and potential benefits to the use of CIs. Some of these additional benefits are common to all CIs, but others are specific to a smaller group of indexes.

Quantification of Condition

The CI scale is a standard language for describing the general condition of a facility, which is the simple underlying intent of CIs. It was desirable to make the quantification as objective as realistically possible. Subjectivity varies between CIs. The use of numerical condition indicators allows for convenient data storage and handling by computer, and the condition indicators can be included in mathematical expressions. The quantification of condition makes most other benefits possible.

Identification of Specific Problems

With any inspection process exists the possibility of finding unknown problems. As a standardized procedure with established items to look for, however, the CI inspection assists the engineer in inspecting and becoming more familiar with his/her structures. The Gate CIs implement inspection procedures not previously used within the Corps. The CI inspection procedures can also be used by project and area or District office personnel in identifying problems. Local people sometimes miss items that they walk by every day. At other times they understand that something is not right but cannot identify the cause. The CI inspection is intended to catch these items, as illustrated in the **Anecdotal Case Histories** (p 26). Specific problems can often be solved locally by minor adjustments or small fixes. Fixing items at this stage is, of course, very important so that small problems do not evolve into major ones.

Investigation of Concerns

An obvious objective of CIs is to increase understanding (directly or as a communication tool) of a structure based on quantification of its condition. Additionally, most CIs provide some increased level of understanding of specific problems. The Gate CIs do the most to collect information that increases knowledge about the distresses. This source of information can be particularly important between dewaterings when much of the structure cannot be visually observed. (Diving may offer a limited visual inspection that is adequate for many specific concerns.)

The geotechnical area within the Corps has had limited application of risk analysis methods. The Embankment Dam CI may be a useful tool within this area for both small and large repairs. The evaluation process provides a framework for intense, focused discussion of areas of concern by geotechnical engineers. Although currently available information on performance parameters (being developed by CECW-EG) is limited to one published paper, it appears that

the Embankment Dam CI and performance parameters should be highly complementary. Together they could prove to be more valuable than when used as separate tools.

Creation of a Condition History

Based on a set of CI condition histories, the rate of deterioration can be estimated, which has many potential uses in the budgeting process. CI historical information is useful in determining trends and planning out-year expenditures and complements the Periodic Inspection process (see Chapter 5, **CI Relation to Other Project Inspections**). CI information is often more concise and can be easier to use than contract documents or Periodic Inspection reports. Although it may not explain the entire situation, the quantified information is usually less ambiguous than descriptive narratives. Repetitive problems may be exposed by the review of CI information.

CI inspection information provides a systematic way to store data for future reference and comparison. Comparisons can be done with previous inspections at the same site and with inspections and performance at other sites with similar conditions (e.g., the same operating equipment, a similar anchorage design, similar gates, etc). The consistent organization of the data seems essential for historical and diagnostic purposes. At the very least, it allows collection of data in a more systematic manner over the Corps domain as opposed to collecting data in a format that varies from site to site.

Supporting Documentation for Presentation of Decisions and Prioritization of Work

CI inspections and ratings provide reassuring information to managers for decisions that are often largely subjective in nature. It can increase the confidence of all parties in the decision process, including the engineers. Anecdotal experience indicates CI information has the greatest effect on budgetary and planning managers with limited engineering experience. These are often the people with whom engineers have the most difficulty communicating. CI information helps engineers clearly assert their position and reasoning.

CIs provide information that can assist in determining operational funding levels between Divisions and Districts, which are essentially independent operations with centralized funding distribution. CIs can be helpful in prioritizing work packages and could be used within a more comprehensive prioritization process.

Although it does not always present the whole picture, quantified inspection information can be used to assist in prioritizing more detailed risk analysis studies. Districts need better tools for determining whether to spend large amounts of money on the research and reports necessary to obtain rehabilitation funding. Additional tools based on CIs could be developed to better assist in these highly subjective prioritization decisions. This potential benefit is discussed further in Chapter 4, **Reliability and Risk Analysis**.

As a CI, the Embankment Dam CI includes more analysis of repair priorities. It does a good job of quantifying the known geotechnical concerns and priorities for a project. It can be helpful in prioritizing geotechnical dam safety concerns and as a screening tool for piping and seepage problems. It includes a process for evaluating monitoring and instrumentation priorities and provides a framework for the geotechnical engineers to determine and prioritize their concerns regardless of the current level of knowledge or analysis for specific concerns.

Information Source for Contracting Scopes of Work

This benefit is most clear for the Coastal CIs. The CI database includes information on location and size of areas needing repair.

Quantification of Condition for a Project or a System

Project level "summary" CIs based on the component CIs have not been created as there has been some disagreement on the need for these summary indexes. Those opposed to summary indexes have looked primarily at the use of condition quantification information for reliability assessments. Others would like to have summary indexes for additional reasons that may be less important. These reasons include developing a system-wide condition history and developing a CI-performance relationship.

A system-wide condition record serves multiple purposes. As Congress continues to reduce budgets, it is important to know if this reduced funding is causing deterioration in projects and, if so, to have a measure of the severity of deterioration. Funding levels can be adjusted based on the trend in CIs or a target CI. CIs can also help in system management, which is particularly true for structures such as riverine dikes where the system may include thousands of dikes.

Investigations of maintenance and repair (M&R) work packages submitted in the ABS system (discussed in Chapter 3) indicate that the work within a single work package often cannot be appropriately reflected by a single CI rating. A method

for combining multiple component CIs of single or multiple component types may be needed.

A Training Tool

All CIs provide some guidance to technicians and new engineers that lack the experience to know what to look for when assessing condition and performance of project structures. Some CIs (e.g., Gates) go further and show engineers how to investigate their structures at a level of detail not covered by other inspection guidance. This is true for a gate in a dewatered state but even moreso under normal conditions when much of the gate is hidden under water. As previously stated, various CI procedures direct people to look at things they may not have before and to make measurements not previously done. Even experienced engineers can learn new skills based on a general CI approach and specific CI procedures.

The Embankment Dam CI is clearly an example of a good training tool. The process clearly illustrates the reasoning process used by engineers in their decision making by providing a framework that focuses on specific concerns. Both new and experienced engineers can learn what others think about the dam.

A Data Source for Detailed Risk Analysis

Risk analysis is data intensive. Often the desired data is unavailable. CIs can help when alternative methods must be used. This potential benefit is discussed further in Chapter 4, **Reliability and Risk Analysis.**

A Simplified Estimate of Reliability

Detailed risk analysis is time intensive and expensive. Simplification of detailed procedures for initial review and prioritization of issues can be of limited value and misleading. Depending on the component CI, they can assist or be a substitute process for estimating reliability. This potential benefit is discussed further in Chapter 4, **Reliability and Risk Analysis**.

Why Districts Currently Use CIs

CIs were initially designed for prioritizing nondeferrable nonrecurring (Level 2) O&M work packages at the HQUSACE level, but to date they have not been used for that purpose at any level within the Corps of Engineers. Other benefits have been realized, however, when CIs are implemented by Districts and project

sites. (A "project" as used here is a collection of infrastructure that manages a water resource as authorized by Congress.) Of the Districts that have pragmatically implemented the CI systems, there are two universally recognized and immediate paybacks: (1) The systematic "checklist" approach to condition inspections is a regimented and consistent method of establishing "benchmarks" from which comparisons can be made, trends can be identified, and damage quantified, and (2) The procedures keep engineers and O&M personnel "up close and personal" with the structures; dangerous situations with a potential for substantial costs are discovered, where ordinarily such distresses go unnoticed and unmeasured. A potential for trouble often is not visible to the naked eye, but simple routinely executed measurements will point directly at a set of likely or readily identifiable causes. More often than not, such abnormalities can be addressed through routine in-house repair or readjustment, but might develop into much more serious and problematic situations if ignored (see **Anecdotal Case Histories** later in this chapter).

How Districts Implement CI Inspections

Nearly all CI inspection procedures were conceptually designed to be executed by site or field personnel. Most Districts, however, opt to use combinations of site, Engineering, and Operations personnel or occasionally contractors. The brief descriptions that follow illustrate how various districts have implemented CIs, including instances where USACE Districts have successfully expanded the intended objectives and resulting benefits of CIs.

Rock Island (CEMVR)

Navigation – Since the mid-1980s, Rock Island has consistently volunteered expertise for CI development for miter gates, roller gates, tainter gates, operating equipment, and concrete. Rock Island began doing the CI inspections regularly in 1994. From 1994 to 1998, inspections were completed through a reimbursable contract with CERL. During FY99 Rock Island decided to train a team of inspectors composed equally of Engineering and Operations personnel. The team executes the inspections and incorporates the procedures into the Periodic Inspection process. CI inspections are now performed in-house every 5 years with the data collected prior to the Periodic Inspection and included in the Periodic Inspection Report as part of the permanent record. During training exercises it was demonstrated that the in-house team could inspect 4 miter gate leaves, and 4 sets of miter gate operating equipment, and the concrete at a single chamber 600-ft lock (including the dam with approximately 10 gate bays) for about $5,000 (see Table 2). Though not demonstrated, it can be assumed that

the same team could inspect a dam tainter gate and its operating equipment in less than 2 hours. Rock Island has clearly indicated that they want the CI to be useful for identifying minimal operational funding requirements; and further, that O&M allotments based on actual needs (as opposed to historical trends) will become a standard. It was also noted subsequent to the training exercise that the Operations personnel are absolutely capable of executing the gate and operating equipment inspections on their own; however, CEMVR's Engineering Division prefers to have their geotechnical engineers inspect the concrete.

Table 2. Post-CEMVR training estimates for future planning.

Miter Gate & Operating Equipment – Per Lock				
Personnel	**Rate**	**Hours**	**Cost**	**Description**
Team	$ 148	12	$ 1,776	Inspect
Team	$ 148	4	$ 592	Travel
Engineer	$ 76	5	$ 379	CI & Report
Per Diem	$ 115	4	$ 460	If required
Section Chief	$ 95	3	$ 284	Review
			$ 3,490	
Navigation L/D Concrete – Per Lock				
Personnel	**Rate**	**Hours**	**Cost**	**Description**
Engineer	$ 76	4	$ 303	Inspect
Engineer	$ 76	4	$ 303	Travel
Engineer	$ 76	2	$ 152	CI & Report
Per Diem	$ 115	1	$ 115	If required
Section Chief	$ 95	3	$ 284	Review
			$ 1,157	

Tulsa District (CESWT)

Navigation, Flood Damage Reduction, Hydropower – Tulsa District served as a test area for CI development in the 1980s. In FY99 the Tulsa District Engineer asked that CIs be evaluated by the District as a potential budgeting tool to assist in prioritizing O&M work packages across business areas. This level of implementation is a first in the USACE Districts and aligns with the original research intent. The demonstration for Tulsa included two navigation locks and dams, a hydropower house, and three embankment dams. Recreational projects (with pavements and buildings) may be included at a later date but were not a part of the demonstration. Tulsa District is in the process of training Operations and Engineering personnel to execute the CI inspections and data analysis.

Saint Paul District (CEMVP)

Navigation – St. Paul volunteered expertise and test bed locations early in the program. They used CERL to accomplish a majority of their initial navigation inspections (miter gates, operating equipment, and concrete) and more recently have used a private sector contractor to execute the inspections. Contracting at St. Paul has been necessary because of a lack of manpower and the time to accomplish the work in-house. They have performed benchmark CI inspections for all but the upper two of its Mississippi River locks and dams (miter gates, operating equipment, concrete, and some tainter gates). This accomplishment afforded a unique opportunity when they were able to quantify the amount of damage caused by a miter gate/barge impact. A CI procedure was performed on the gate after the accident and compared to CI data from an inspection performed on that gate 2 years earlier. Though the damage was significant, the gate was still operable. The raw data (and the associated indices) indicated the gate was still in safe operating condition, but the amount of wear/damage was identified objectively. This instance of benchmarking also demonstrates its potential use in litigation.

Nashville (CELRN)

Navigation – Nashville also volunteered expertise and test bed locations early in the program. They have been executing CI inspections using in-house personnel on miter gates, tainter gates, operating equipment, and concrete. Nashville is a strong proponent of the miter gate inspection process. They are less concerned with the indices per se than they are with the actual measurements and the procedures used to obtain them. (Item of note: Nashville's lock inventory is comprised of mostly high lift locks where the miter gate length to width ratio is less than 2.)

Buffalo District (CELRB)

Navigation – Buffalo has been performing CI inspections for miter gates, concrete, and steel sheet pile. They have been performing (and been reimbursed for) these same inspections for another USACE District. The Cleveland Port Authority reimbursed Buffalo for inspection and rating of their steel sheet pile and is using the results to identify and prioritize reaches for repair.

Pittsburgh (CELRP), New Orleans (CEMVN), Jacksonville (CESAJ)

Navigation – These Districts have used reimbursable contracts to get CI results for various navigation and/or flood damage reduction structures. They believe that, for a variety of reasons, it is necessary to have outside specialists perform the inspections. (Practice has shown, however, that Districts using in-house personnel find great value in having a "sense of feel" for what the numbers (data) tell them.)

Huntington (CELRH), Louisville (CELRL), Wilmington (CESAW), Tulsa (CESWT)

Flood Damage Reduction – Embankment Dam CI workshops were held in each of these Districts. The exercises included the evaluation of a District dam. In Tulsa, three dams were rated. The Huntington workshop had difficulties with software and the dam selected for inspection had no significant problems, which resulted in a less than successful exercise. In Wilmington and Louisville, the exercises were much more informative. The result was a better understanding of many known problems and highlighting of some problems that had not been noted previously. The engineers were impressed by the depth of discussions during the process and felt they better understood the structures afterward and could more confidently manage their maintenance and repair. Louisville was particularly impressed with the potential for using the system to train journeyman engineers about both what to look for in general and the history and concerns of the structures.

All USACE Districts

Hydropower – The CI manual was distributed to all projects, and District and Division offices. CIs are required for all hydropower work packages in the budget. The other main use so far has been in conjunction with major rehabilitation studies. In these cases, the equipment in question is analyzed fairly rigorously using the tests and inspections described in the manual, and incorporated into the rehabilitation risk analysis. The data are used in conjunction with survivor curves to predict probability of failure using Monte Carlo simulations. The bulk of this data has been collected for turbines and generators. Survivor curves for other equipment have just become available. Similar to embankment dams, hydropower CIs do not use a custom-designed inspection or site visit. Inspections called for by regulatory compliance ensure that all the data required by the hydropower CI are on file.

Implementation of the Embankment Dam CI

The Embankment Dam CI process is intended for use by geotechnical engineers with solid geotechnical education and experience and a good understanding of the physical characteristics, history, and condition of the dam being inspected. Other disciplines may contribute to the evaluation, but the geotechnical knowledge and experience are critical to the process. It is recommended that the process be completed by a minimum of three such engineers although the third could be a less technically knowledgeable facilitator. The upper limit on the panel size is highly dependent on the level of participation and the personalities within the group. The preferred number of participants appears to be from 5 to 8, but 10 participants might be a reasonable upper limit on the group size. If there are more than 10 contributing participants, the process may be slowed and become less efficient and effective. The process promotes interaction between the members, which has been a positive experience and is considered critical to the success of the CI. The group will need approximately 1 day to evaluate a complex dam with known problems and concerns about its performance. Simpler dams will take less time. The process becomes trivial for dams that have no known problems. Subsequent CI ratings for an embankment dam will require much smaller efforts unless dam conditions have changed significantly. Of particular note, the Embankment Dam CI does not require an additional inspection or site visit. Inspections performed by policy and through normal business practice generally ensure that all the data required by the Embankment Dam CI are on file.

The Embankment Dam CI formalizes and expands a process already present in most Districts. Through group discussion, budget packages are sorted and prioritized. This CI merely creates a framework for more detailed conversation and organizes the information. The formal process enhances the possibilities for holding a constructive dialogue. By organizing the information, knowledge can be transferred to less experienced or future employees, serve as a historical record of past priorities, and perhaps most importantly, serve as a tool to communicate concerns and priorities to higher levels of management.

The Embankment Dam CI focuses primarily on analyzing existing inspection data for specific parameters and the impact of these parameters on the integrity of the dam. The CI is sensitive to the unique characteristics of each dam by assuring proper consideration of the uniqueness in the development of the CI. To achieve this, the Embankment Dam CI evaluates existing inspection information based on the subjective determinations of knowledgeable engineers. The Embankment Dam CI thus provides a guiding framework that focuses attention on specific issues and quantifies the findings.

This particular CI is most important in situations where multiple concerns are present. Dams without any current concerns may not merit a detailed evaluation such as the CI. Luckily, the effort required is closely correlated to the level of uncertainty and divergence of opinions about the problems present. Re-evaluations of a dam will be very easy unless conditions have changed.

It may take a number of years to complete the process, but all embankment dams should be evaluated using the CI. Dams with more problems or more serious problems should be evaluated first. Many dams are in good condition and there may not be anything learned by going through the process, but there are two reasons to look at *all* dams: (1) It will further confirm that no problems exist and (2) it becomes a good record of past condition.

It is most important to evaluate dams with significant concerns requiring maintenance and repair first. Re-evaluations will be quicker and easier depending on the level of change over the period. No change will require little effort. Significant changes may require as much effort as the original evaluation.

The primary benefit of the evaluation is to the participants, who should have greater clarity and confidence in their opinions and concerns for the dam. Their plan of action may not change, but the CI should help them communicate their concerns.

Common CI Perceptions and Misperceptions

Introduction

The intent of this section is to clarify many issues related to implementation of CIs. Clearly, the corporate policy on CI usage is ambiguous. In fact, there is no stated policy except that related to O&M budget work packages as stated in the Budget EC. This lack of policy is in part due to changes in the CIs and changes within the Corps since the mid-1980s when CI work was initiated. As a result, there are many divergent opinions on how CIs should be and will be used. Project personnel, District Operations, District Engineering, CECW-O*, and CECW-E* each have different perspectives that result in the different understandings.

* CECW-O: HQUSACE Operations Division; CECW-E: HQUSACE Engineering Division

The following remarks should enhance everyone's understanding of what CIs are and how they may best be used. The remarks should not be interpreted as a formal policy statement.

Appendix F lists "Problems, Benefits, Questions and Opportunities" relating to CIs. It is a very informal list of factors affecting CIs and their implementation. Review of this list will help the reader understand some of the difficulties in implementing CIs under a consistent policy with full participation of the Districts.

Common Misconceptions

1 – Budget decisions will be made solely on the basis of condition index ratings.

The information gathered to make CI ratings has had some impact on District funding decisions. The actual CI rating numbers have had less impact and will continue to have limited impact in the foreseeable future. At a Corps-wide level, the CIs may result in a request for further information or justification of budget prioritizations. It is envisioned that CIs will gradually have more effect as they are used more, but they do not consider all parameters. Budgeting prioritizations cannot be made based solely on CI numbers.

CIs do not address all variables important to the budget process. More research has been programmed to incorporate additional decision parameters, further analyze the information, and project the effect of repair options. The intent is to create a relatively simple process to add some quantitative measures of relative or dollar-based priorities among ABS work packages. Such a tool is expected to be used for gross ranking; it is not realistic to expect this process will ever consider all possibilities. It can only provide better information to support decisions that are ultimately made by people. It is uncertain whether the prioritization process will be limited to some repairs, all repairs, M&R, or operations, maintenance, and repair.

2 – This tool will be used to replace technical input from engineering.

Many of the CIs developed are tools to collect inspection information. The CI number should reflect the information, but M&R decisions have to be based largely on the raw information. The CI process is intended to help collect, evaluate, and communicate technical information and is intended to corroborate and support technical input from Engineering, not replace it. The Embankment Dam CI is the best example of this. It is based almost totally on the knowledge of the engineers and merely provides a framework to collect and quantify their technical input.

3 – Condition indexes are too expensive.

The use of CIs definitely involves an expense. Any other methods of inspection or evaluation also involve expenses. All methods must be used appropriately. The actual cost of some previous CI implementations is less than many people assume. This was discussed more fully earlier in this chapter in **How Districts Implement CI Inspections.**

4 – CIs are intended to be a measure of condition, failure probability, repair priority, and functionality of a component.

CIs are primarily a measure of condition. They measure wear, deterioration, and other deviation from "like new" or good design. The CIs often include consideration of failure probability, repair priority, and functionality or have some implicit correlation to one of those parameters. It is not possible to correlate to all those parameters at once, and CIs generally have limited correlation to any of the parameters.

CI Simplification

One objective of continuing research has been to simplify CIs. In others words, how can we retain most or all of the value with less effort? A sponsor review of CI-related research was held in November 1999. At the meeting, a goal was set to retain 80 percent of the value with only 50 percent of the effort. Granted, measuring the value and the effort level is largely subjective, but what if an 80/50 target cannot be reached? The first question was whether the 80 percent value should be held constant and the effort level minimized or the effort level held constant and the value maximized. Further reasoning suggested that it would be better to maximize the difference in the effort and value (most value for least effort) with little or no consideration of the 80/50 goal. If there was more than one option for simplifying a CI, it would be better to optimize the value relative to the effort. If so, the option that maximized the difference in effort and value might not be the optimum solution. If 80/50 is truly the optimum goal, maybe the option that is closer to the 80/50 goal would be optimum. The optimum might also be based on or impacted by other parameters. Another reason the 80/50 goal should not be fixed is because there are real differences in the level of effort and even the resolution of the current CIs. Restated, the starting point is not always the same. Some CIs require more effort and some CIs give better results.

The goal of CI simplification is to significantly reduce the effort necessary to obtain most of the benefits. One approach would be to eliminate parts of the inspection that add minimal benefit and find easier methods to collect the remaining information. Modifications to CI procedures that allow the same information to be collected with less effort should also be considered. Another approach is to minimize the frequency and extent of inspections. This can be accomplished by performing a simpler inspection to assess the need for some or all of the CI inspection procedures and developing guidance for CI inspection frequency. Recommendations for inspection frequency should consider the current condition. The CIs are listed below, and examples are given suggesting when a modified (simplified or partial) CI might be preferable.

Gates: A full CI inspection is recommended at least once to serve as a benchmark. As applicable, CI inspections should be performed following suspected severe loadings or poor performance and prior to deterioration-related repairs.

Miter and tainter gates: High head gates should be regularly inspected (i.e., every 5 years). Low head gates could be inspected less frequently, inspected using simplified CI measurements, or with a reduced set of measurements. Some sampling may be adequate for a spillway with many identical gates.

Sector gates, tainter valves, and butterfly valves: Assess simplification, reduced frequency, and partial application possibilities.

Operating equipment: The original CI procedures for operating equipment assemblies are simplified.

Hydropower: These CIs are largely based on existing inspection information. Simplification may apply to some information not collected in other inspections. Assessment of MICAA* inspection and evaluation procedures developed by Iris Power Engineering, Inc. will be made at (http://www.irispower.com or http://www.irispower.com/softlist.htm).

Embankment dams: Problem dams should be fully evaluated using the embankment dam CI. The CI evaluation is a good opportunity for the responsible

* MICAA: The Machine Insulation Condition Assessment Advisor is an expert system developed to guide maintenance personnel through the winding assessment process, producing an evaluation of the rotor and stator winding condition of large high voltage rotating machines.

engineers to systematically evaluate their understanding of a dam. Dams with less severe problems (CI>75) could probably be evaluated using a simplified CI procedure. A simplified procedure would quantify the condition but probably would not help the evaluators better understand the dam. The embankment dam CI procedure is typically unnecessary for dams with no known problems (i.e., CI>95). This CI includes an evaluation of failure modes and monitoring devices. Some Corps dams do not have monitoring devices that warrant a CI evaluation.

Concrete lock and dam monoliths: Eliminating the boat survey of the interior chamber walls can significantly shorten lock monolith inspections. Usually the effect on the inspection results is minimal, but in some cases the advantages are small if any. When problems are visible from the deck, closer viewing from a boat may be more useful. Also, if a lock gate inspection includes a boat survey to view the gates, the concrete can be surveyed at the same time. Other than the boat survey, the only other methods identified to possibly reduce inspection effort are to increase reliance on sampling or to reduce inspection frequency.

Coastal structures, dikes, revetments, and steel sheet pile: Simplified procedures for CI inspection of these structures have not been considered.

Discussion of Function Within CIs

Subcomponent CIs are generally true condition ratings. When you create a component CI based on subcomponents, the relative importance of the subcomponents needs to be considered. The primary basis for determining these relative importances almost has to be based on the functional importances of the subcomponents. As a result, the component CIs have an inherent consideration of function. Component CIs may not include consideration of all aspects of function, but does include some. The examples below should illustrate that function can have many meanings.

Functional example for a breakwater:

- Loss of armor exposes the breakwater to accelerated deterioration
- Loss of armor reduces the height of the breakwater and may allow increased waves in protected areas
- Regardless of the condition, the breakwater is designed incorrectly and will not provide adequate protection from waves

For gates:
- Leakage
- Wear, misalignment, hinge friction, anchorage movement, paint loss, etc., that currently interferes with operation, may eventually do so, or increases deterioration
- Gate improperly designed for loads
- Gates inadequate to pass required flow

For concrete:
- Cracks allow increased deterioration from freeze-thaw
- Concrete deterioration on deck surface obstructs work and creates safety hazard
- Concrete volume loss affects stability
- Concrete monolith could be under-designed for function (hydraulic load resistance)
- Lock is too small for tows
- Lock is large enough, but an additional lock is needed for traffic

For embankment dams:
- Deterioration creates maintenance requirements
- Deterioration increases dam safety risk
- Design does not meet dam safety standard (creates downstream hazard)
- Project does not provide adequate flood control benefits downstream

Obviously, not all these functional criteria are considered within CIs, but we cannot help but consider some of them. Differences in CIs result from differing choices and abilities to consider function in each CI. At a higher level such as a summary index, the implications of function may be even greater.

Anecdotal Case Histories

Many times CI inspections have surfaced information that was important in the proper maintenance of gates and their operating equipment. Some findings result simply from a close visual inspection of the structures, while others result from the measurements taken during the process. The repair requirements vary, but frequently the minor repairs indicated have the potential to greatly extend the life of various subcomponents. Following are representative samples of these findings.

Quoin Bearing on Miter Gate

St. Paul District at Locks 3, 5, and 7 – The top girder quoin bearing block did not make contact with the corresponding wall contact block under full head load. The wall block on Gate #3 at Locks 3 and 5 and at Gate #4 at Lock 4 was either not set properly or had become misaligned. This resulted in a load transfer condition through the gudgeon pin that the system is not designed to handle.

Nashville District at Guntersville Lock – The anchorage linkage arms were not adjusted properly to allow free mating of the quoin contact blocks as the gates were brought to the mitered position. The blocks made premature contact before the gate was close to the mitered position. This contact caused the two parts of the blocks to bind up and grind together. It also overloaded the gudgeon pin by pushing it out from the wall in addition to the hanging weight. This problem became worse in cold weather as the gate length became shorter. At times the blocks bound up so tightly that the gate could not come to full miter and close properly. The gates would finally be pushed closed by head pressure as the lock chamber emptied.

Rock Island District at Lock 19 – A portion of the wall quoin contact block was missing on Gate #3.

Gudgeon or Hinge Pin

St. Paul District at Lock 5A – Barge impact damage to the top anchorage and hinge assembly of Gate #2 was quantified by comparing post-collision measurements with baseline measurements from a previous CI inspection record. The measurements were able to quantify gudgeon pin bushing deformation due to the collision while also clearly identifying anchorage components that had not been damaged.

Rock Island District at Chicago Lock – A sector gate inspection performed for documentation of overall deterioration indicated excessive wear in three of the four upper hinge pins. Further investigation indicated two of the hinge pin bushings were frozen to the pin and rotated with the pin, thus wearing on the casting metal of the anchorage yoke. The third pin was also frozen to the hinge pin bushing, but in this case the gate frame rotated about the pin, wearing on the steel plate gusset framing.

Sector Gate Anchorage

New Orleans District at Bayou Sorrel Lock – Anchor bolts securing the anchorage yoke to the concrete gate block monolith were severely corroded just inside the pipe sleeve embedded in the concrete. The original bolt diameter was approximately 1-1/2 in. and the corrosion had "necked" the effective diameter down to 3/4 in. or less. Once the problem was discovered and the District office advised, an emergency repair effort was initiated within 2 weeks and the problem permanently repaired within the year.

Operating Equipment

Rock Island District at Marseilles Lock – During a research trip we were shown a pinion gear bushing on a miter gate operating system for Gate #2 that had some movement at the base. Later, during a CI inspection, the same condition was documented as excessive wear and movement that required immediate attention. The repair was made within 3 months of the notification to the District.

New Orleans District at Port Allen Lock – During a research trip to investigate problem types on gear racks with hydraulic cylinder push rods, it was discovered that one of the gates had excessive play and a gap between the gear rack and the reaction rollers. This excess play allowed improper tooth contact that could have resulted in overloading the tooth and potential tooth damage.

Cracks

Rock Island District at Brandon Road Lock – During a CI inspection of the upper miter gates, a crack was discovered in the skin plate on the downstream side of Gate #4. The crack was reported to the District as a concern. The location of the crack on the downstream side at the bottom of the gate and the lack of other surface damage to the skin plate raised the question that the crack might be the outward expression of other structural problems. The skin plate in the proximity of the crack is the downstream cover of the downstream flange for the bottom girder of the horizontally framed gate. To our knowledge, no further investigation by the District has been done, nor has any further problem developed.

3 Automated Budget System Database

The original goal of CI-related research and development (R&D) was to develop a tool to assist in the prioritization of work items in the annual O&M budget. The ABS is the CW management-reporting tool that ties the O&M budget together. ABS operates at all hierarchical levels of management within the Corps — from project to District to Division to HQUSACE. Districts create work packages and determine the relative priority of the packages. These priorities are entered into ABS, which includes algorithms that assist in creating rankings across Districts and Divisions based on historical funding levels.

Where CIs exist, CI data are required for O&M work packages in ABS. The category codes that require CIs in ABS include *Navigation* (ABS Work Category Codes (WCC) = 601XX, above $100K), any *Breakwater and Jetty* work packages (WCC = 611XX), and any *Hydropower* work packages (WCC = 603XX and 613XX). For these particular packages, ABS will not move to another sequence until a CI integer is entered for the work package. Engineer Circular (EC) 11-2-177 states that:

> CI procedures are being developed at the individual component level, (e.g., a miter lock gate, steel sheet pile structure, etc.). This generally lends itself to the work packages used to describe maintenance requirements in the Windows - Automated Program System (WINABS). Therefore, a CI should be entered for each work package record for which a CI procedure has been developed in the following Work Category Codes

The budget EC thus implies that CIs have one-to-one correlation with the O&M work packages; however, this is not the case in many instances and no instructions are provided to assist Districts when the one-to-one correlation does not exist.

To evaluate the correlation between CIs and O&M work packages, several ABS databases (FY99-00) were collected from Districts in the Mississippi and Ohio River valleys. All work packages that contained CIs were captured to be reviewed. Of the records containing CIs, 395 records were selected. The work packages all dealt with hydropower or navigation. For each record that was ex-

amined, an evaluation of the "correlation" between the tasks described and the associated CI was made.

When the task described could be "suitably" represented by a single CI, the correlation was described as "1" or "Strong" (e.g., the left miter gate leaf at L/D #15 needs replacement). A strong correlation was assumed when the task described work on a single structural component, for which a single CI exists.

The correlation was considered "2" or "Indirect" when the task described maintenance for multiple structures (e.g., several tainter gates or more than one miter gate leaf) or when the task described work needed only on a subcomponent of a larger structure. In the latter instance, a CI exists but in all likelihood the CI for the parent structure is reported instead of the CI for the subcomponent.

The correlation was described as "3" or "Weak" if no CI system for the component exists. A "Not Applicable" (N/A) rating can be used for those work packages for regulatory inspections, reports, studies, and so on. Although this review was cursory, the immediate results clearly identify problems inherent in the assumed one-to-one correlation of existing CIs-to-ABS work packages. (Note that ABS information can be used to indicate the general classes of structures or components where further CI development is needed.)

Table 3 indicates that a relatively small percentage of sample CIs entered into the database actually make sense in terms of capturing the condition level of the component(s) described in the task description and/or task justification. That is, the CI "successfully" captures the state of deterioration of components within a given work package in a relatively small number of cases.

By far, the most frequent reason for describing the correlation as "Indirect (2)" was that multiple structures were addressed in the task description, and sometimes completely different structure types (e.g., multiple gates and sets of operating equipment) were included. Although CIs exist for nearly all of the components in the task description, the single integer field allotted for CI within the current ABS does not adequately convey the physical state of numerous structures and/or components. A multiple component CI (composite CI) or additional ABS fields may be more successful. This problem is being addressed in FY00-01 R&D efforts.

Table 3. Successful capture of sample CIs in the database.

# ABS Records	Strong (1)	Indirect (2)	Weak (3)	N/A
395	57	68	183	87
Percent Successful Capture	18.5%	22.1%	59.4%	

From the “Weak (3)” category where 183 records were examined, a CI does not yet exist for the component (or combination of components) described in the work package. Most often such tasks described maintenance on various electrical equipment (generators, wiring, control systems, dials, gages, etc.). The most commonly listed work package (15 percent) was paint and/or protective coatings for which a CI does not exist. (Note that all CIs do consider rust and corrosion, though this may not be a suitable substitute for a CI for protective coatings.) The remainder of this category is mainly replacement of electrical equipment, controls, and hydropower-related work, with miscellaneous items such as signage and elevators included. Other items include lift gates and service bridges. Creation of CIs for these components would significantly reduce the number of components and work packages without a related CI.

Also included in the “Weak (3)” category were several hydropower components for which outside expertise is needed to determine to which category they belong. The expertise to evaluate the CI correlation for these particular components resides at the Hydroelectric Design Center (CENPW-HDC). Plans have been made to continue this evaluation with HDC involvement, focusing specifically on hydropower work packages.

The conclusion that can be drawn from this analysis is that often the CI loses its meaning once it is placed in the ABS. A need has been identified to establish a set of rules that are *simple and easy to understand and use* for entering the CI (CIs or composite CI) into the ABS database. Many simple ideas are immediately obvious: for multiple structures of one type, the lowest and average CIs could be reported. Rules that separate apples from oranges could be embedded within the system. Such rules must ensure that the inherent meaning of CI information relative to work packages is maintained in its circuit through the budget cycle.

Cautionary Notes Regarding Preliminary Evaluation of CI within ABS: Reading this chapter is likely to lead one to believe that CIs have no relationship with most work packages submitted in the ABS system. Comments are made suggesting how some packages could be better related to CIs because most of the sample ABS budget packages have no apparent relationship to CIs based on the information presented within ABS. Here are some other possible considerations that may cast a more positive light on the CI/ABS relationship:

1. The statistics were for the number of work packages, not the cost. It is suspected that the packages with a stronger correlation to CIs were generally larger cost items. The data need to be analyzed based on relative cost of work packages.

2. As mentioned earlier, some budget packages with possible links to hydropower CIs were classified as weak correlations due to a lack of knowledge on what the hydropower CIs covered. The ABS databases that were analyzed included very brief work descriptions that are difficult to categorize without a more thorough knowledge of hydropower O&M.

3. It is not clear which packages are repair and which are maintenance. The correlation may be stronger for repair packages.

4. Studies and analyses were considered to be "Not Applicable," but the prioritization of these packages could be associated with the CI for the structure being studied or analyzed. Also, the electrical packages included dials and gages that may be for instrumentation of structures. Instrumentation could be associated through the CI of the structure being investigated.

4 Reliability and Risk Analysis

Introduction

This chapter presents various uses of CIs within the reliability and risk analysis framework. These ideas should be looked at as undeveloped potentials and not realized benefits. Based on previous experience, they appear reasonable and logical. The use of CIs within a risk analysis framework has not been developed and tested for accuracy and level of benefit.

Inspection and risk analysis are both important in the determination of optimum operation, and maintenance, repair, and rehabilitation (MR&R). There are many methods for accomplishing repair, evaluation, maintenance, and rehabilitation. Some methods are more rigorous than are others. Even when the inspection is informal and the risk analysis is implicit, both are required for facility management. Some possible methods are briefly explained in the remainder of this section. Effective management of a facility may include the use of all methods. Corrective, use-based, and condition-based maintenance are more fully discussed and compared in an article by O.D. Dijkstra (1996).

Corrective (Breakdown) Maintenance

This method is usually considered to have negative consequences. It is often referred to as "fighting fires," meaning that such work is an emergency and very few preventative measures are taken. Such repairs are often very expensive relative to proactive M&R. Despite this negative connotation, in some cases it is a reasonable option. A simple example is a light bulb. Rarely is there a reason to change light bulbs before they burn out. The reasoning for more complex components is usually similar. If breakdown maintenance causes no increased repair cost or loss to the user, proactive repairs may not be economically justified, especially if there is excess capacity and production or usage can be shifted to other facilities.

Use-based or Scheduled Maintenance

This method is very effective for small actions such as lubrication of mechanical equipment. In such cases, it is usually cheaper and easier to complete the main-

tenance than evaluate the need for such maintenance. The greatest potential for savings is through optimizing the schedule. As the cost of MR&R increases, it becomes increasingly important to accurately assess the need for MR&R. Unless the need is truly uniformly cyclic, costs can be saved by determining the need for each application of scheduled MR&R.

Condition-based Maintenance

The condition of the component concerned is evaluated through inspection and analysis of information. Repair needs will be determined based on the condition. This method is very effective in many situations. Experience may have shown that, if a particular situation exists, a specific MR&R action will be beneficial. At its most effective, condition-based maintenance is the result of a trial and error process, with most errors having been found and near-optimum solutions reached.

The condition may be determined through a formal standardized process such as a CI, a "best judgment" approach such as the Periodic Inspection, or some combination of the two. Combination offers advantages of each. The CI communicates the experience of knowledgeable engineers who have evaluated important parameters and quantifies the process to provide consistency across an organization, and the descriptive Periodic Inspection process provides as much structure as possible to evaluation of unique situations.

Probabilistic Analysis

This is often referred to as risk analysis. The objective is to quantify all parameters that influence the benefits of MR&R options. It is an explicit analysis of considerations analyzed more implicitly in the "best judgment" method. It usually also contains numerous subjective judgments. The difference is that the subjective judgments are, as stated, explicit, and they are smaller and less ambiguous. They may be very difficult to estimate, but are generally easier than "best judgment" conclusions. Sensitivity analysis can help assess the impact of specific decisions. It seems important to also quantify the inspection information used in this process.

Basic Reliability and Risk Analysis Information

Risk analysis is a rational criterion for the comparison of events and decisions that have uncertainty. A logical framework can be created to make estimates using time-dependant, distributed probabilities. Reliability is a more specific

type of risk analysis generally applied to structures. Reliability is based on a load-response relationship that is determined by a detailed engineering analysis or by direct comparison to similar structural components and an estimation of performance through historical performance statistics or subjective probabilities. By either method, reliability analysis includes at least a generic consideration of both observable and unobservable conditions.

In a reliability analysis, probabilistic analyses are performed to determine failure and consequence likelihoods. Within the Corps, failure has been defined differently in the Dam Safety and Major Rehabilitation programs. The Dam Safety program uses fall down scenarios that are total failure modes (P_f) of the structure or a major component. Major Rehabilitation reliability analysis is based on a "Probability of Unsatisfactory Performance" (PUP) that is based on simpler modes of performance such as cracking or deflection. Fragility curves are used to display the results of many probabilistic analyses. The accuracy of a risk analysis is impacted by both the accuracy of the P_f or PUP and by how closely the P_f or PUP relate to all the significant risks that are present. A crack, for example, may have many possible consequences ranging from no operational impact or repair needed in the next maintenance cycle to reduced operation or a structural failure.

Use of CIs in Risk Analysis

During initial development of CIs, there was some investigation into making the CI directly related to reliability. This relationship was determined to be unrealistic given that the CIs were to be based on observable condition measures. They are generally based on standardized inspection procedures with an objective and repeatable quantification of the results and no engineering analysis of the structure. CIs could have been made more like a reliability measure by including unobservable estimates of condition such as age or usage cycles, but this would introduce other difficulties in generating and using the CI information such as setting time-independent benchmarks and making age versus condition comparisons. It would at best be a crude estimate of the unobservable parameters without more detailed analysis including estimated stresses.

There are at least two significantly different ways that CIs can be used within the general reliability and risk analysis framework. First, CIs can be used as a source of quantified condition information for specific components and subcomponents. This can be used to modify predictions based on generic or subgrouping predictions. Second, for situations when a detailed reliability assessment is excessive, CIs can be quicker approximations of reliability. This approach has been

pursued through the Quadrant program, which is described further in the section on **CIs as an Approximation of Reliability**.

CIs as an Input to Reliability

Regardless of the role of CIs, the biggest difficulty in the application of reliability is the availability of desired data and information. The theoretical basis of reliability is sound, but it can be difficult in practice due to questionable decisions made during the process because of insufficient information. In time, this problem will diminish and may largely disappear. It is believed that, when this happens, it will become more apparent that better inspection information is needed in a quantified format.

A reliability estimate is based on a formal (data-based) or informal (subjective) statistical analysis of a group of comparable structures. Typically, reliability studies also include finite element analyses or other analytical studies that take into account the variability of materials, thicknesses, and some geometric properties in addition to stress calculations, loading cycles, and generic approximations of environmental impacts. As the statistical database becomes larger and more specific to the structure being analyzed, the results have a greater accuracy. In most cases, if the comparison set is relatively similar, loading cycles and age are the primary variables in the analysis results. Often, analyses based on these two variables provide reasonably accurate results. By definition, statistical analysis is a very accurate measure of the average reliability in the past.

Accounting for important details like localized cracks, dents, and corrosion is more difficult. How are bearing block gaps incorporated? How are statistical properties of gaps (mean, standard deviation, distribution type) characterized? How are gate misalignments or insufficient hinge lubrication incorporated? Gaps, misalignments, and excessive friction can significantly increase stresses. How do you account for barge impacts? Are all the important parameters known? How are missing parameters accounted for in the analysis? What parameters can be ignored? In other words, incorporating the real, existing structure and its environment into the structural reliability model is essential for an accurate assessment. That may be beyond the state of the art for risk analysis. It is definitely beyond the current state of application.

> The analysis has been restricted to strength-based considerations. Functionality considerations such as … were not considered and will often cause a bridge to be repaired or replaced. (Estes and Frangopol 1999)

If it is understood that the information gaps described in the previous paragraph exist, it is clear that CIs provide valuable information. In addition to quantifying known condition, the CI inspection procedures are useful in finding unknown problems. Many examples are illustrated in Chapter 2, **Anecdotal Case Histories**. Reliability approaches must be calibrated with real life before they will be useful. A predicted failure rate needs real data to be believable. CI inspection and the associated database are certainly a systematic way to begin to collect such data — relating in-situ condition with performance (safety and serviceability).

> The transition from a hypothetical example to a realistic structural application requires tremendous research support. There are many factors including load and strength uncertainties, deterioration prediction models, repair options and costs, discount rates, series-parallel system modeling, and inspection capabilities that must be considered in the optimization process. (Estes and Frangopol 1999)

CIs determine neither the load nor response but instead focus on observable deviations from desired condition (performance). CIs are not a direct measure of reliability although a CI can be an indicator of unsatisfactory reliability. CIs often provide valuable information on the response of the structure to loads. With or without knowledge of the source of the unsatisfactory state, CIs can help determine and quantify actual conditions. Proper consideration of this information within reliability is not simple and will likely include subjectivity. Although care is required, the resulting subjectivity should not be a hindrance to considering CI information since the state-of-the-art application of reliability requires many subjective assumptions. The structural engineering profession clearly needs to continue to move toward the reliability approach, but it must be tempered with real-time observations.

CIs are developed for components of a project, but most CIs also include condition ratings for subcomponents. These subcomponent ratings provide more detailed information that may have more benefit as input for a reliability assessment.

The incorporation of CI information into reliability assessments is not easy or straightforward. Most historical reliability data can be collected on failures or unsatisfactory performances after the occurrence. It is much more difficult to collect the CI data related to a failure. Additionally, if the CI inspection information is used to modify a reliability estimate, it would be best if it could first be determined what the expected CI would be and then the impact of deviation from this expectation must be determined. These are difficult determinations. A

comparison between recent major rehabilitation studies and concurrent CI ratings for those structures may provide some additional insight into how to proceed.

At least two previous studies have investigated the use of CIs as a parameter in reliability studies. In both studies, Bayesian updating techniques were used. The first study (Mlaker 1994) used CIs as a direct measure of satisfactory and unsatisfactory performance. Because the term "unsatisfactory" has significantly different connotations than does quantification of condition and deterioration, this approach had little success. The conclusions suggest that CIs do not discriminate between satisfactory and unsatisfactory items, and their inclusion in reliability analysis provides little additional information. The study uses a small, incomplete CI database that further limits the ability to make conclusions. It contains many low CI ratings. Subsequent investigation of these low ratings indicates they were based on an irrelevant subcomponent. The second study (Ayyub, Kaminskiy, and Moser 1996) also suffers from a lack of data. Given the analysis described in the report, the summary is surprisingly positive regarding the potential for using CIs as a parameter in determining reliability. Although not specifically stated, the conclusions appear to recognize the limitations related to the data. The process presented has the potential of being a good method of incorporating CI information into reliability estimates. Many additional details would need to be addressed. The report also mentions a likely problem with the hydropower CI algorithm. That CI is based solely on the lowest component rating, regardless of the subcomponent's relative importance to the component.

CIs as an Approximation of Reliability

Reliability studies are clearly time-consuming and expensive. That level of effort is most reasonable for large expenditures such as major rehabilitation. In cases where the repair expenditure is smaller, the expense of reliability assessment can quickly become excessive. In that situation, the need for a simpler tool, CI or not, is easily apparent. In all cases requiring extensive analysis for justification, a simpler tool is needed to determine whether a repair project should be pursued and money expended for the reliability assessment.

For M&R activities, even if reliability were not cost prohibitive, it may not be a beneficial tool. Reliability's strength is in evaluation of unobservable parameters that may lead to future events with negative impacts. Normal M&R is more likely to be associated with observable conditions that are often perceived to have a more immediate impact on project operation. CIs are a good tool for iden-

tifying and quantifying these observable conditions. With this situation in mind, a tool named Quadrant was developed (Russell et al. 1993). It is a simple-to-use tool based on subjective condition assessments, elicited approximations of probabilities of interruptions of service, and projections of lost benefits using an incremental analysis economic model.

Within Quadrant, "lost benefits" is very narrowly defined as a per hour delay cost to tow customers dependent on the estimated number of tows delayed by a lock shutdown. The shutdown likelihood and duration are pre-determined subjectively by a group of experts based on a condition-related Summary Index (SI) (indirectly based on CIs). To use the Quadrant model, the user must subjectively estimate the SI before and after the repairs. Repair costs and benefits can then be compared. Although Quadrant probably is not the best example of how well CIs might approximate reliability, it does clearly illustrate the process and rationale of using condition ratings to estimate reliability. Appendix G includes further discussion of Quadrant and additional work proposed in that area.

Risk analysts could possibly use a CI evaluation process such as the Embankment Dam CI as a simpler and less expensive method, replacing some reliability analyses. The Embankment Dam CI has the ability to include consideration of existing reliability analysis and other engineering analyses within the CI process.

Other Benefits Within Risk Analysis

Detailed risk analysis studies may never be performed for some structures. At a minimum, it will be many years before all structures can be looked at in detail. It is important to perform pre-screening to determine which structures most urgently require detailed risk analysis and repair. At the broadest level, the screening might take less than a day for a system of structures. If so, there are benefits to fine tuning the prioritization for structures near the cutoff for risk analysis funding. CIs provide information that can assist in the prioritization of risk analysis studies. Although it does not always present the whole picture, quantified inspection information can be used to assist in determining priorities. As a standalone tool, it is felt that the embankment dam CI goes further in this direction than the other CIs. It is useful for quantifying the known geotechnical concerns and priorities for a project.

The Embankment Dam CI provides a framework for the geotechnical engineers to make their risk-related determinations. The process helps the engineers determine and prioritize their concerns based on any given level of knowledge or

analysis of the concerns. The process also helps pinpoint areas of inadequate knowledge that may need to be addressed prior to a determination on the priority of a risk analysis study for a particular project. The Embankment Dam CI also looks at the hydraulic and structural concerns but in much less detail. The process could easily be expanded to more robustly consider these other areas. Work has been initiated for spillway components in the Risk Analysis for Dam Safety research program, possibly in partnership with HydroQuebéc similar to the Embankment Dam CI.

CI and Risk Analysis Summary

It has been suggested that CIs should correlate to reliability and that, if they do not, they are flawed. It is hoped that the discussion within this chapter will illustrate that CIs are clearly different from reliability and that they should not be expected to perfectly correlate with reliability. CIs are a condition-based measure of performance based on observations and/or measurements at a specific point in time. CIs can only partially relate to reliability because reliability has a time variable and includes both observable and nonobservable conditions. The relationship can best be described as complementary, which would imply little or no correlation, although some correlation should exist. The relationship and level of correlation can best be described by one sentence descriptions of each tool:

- A condition index (as currently applied) is a generic analysis of specific observations and measurements.
- Reliability (as currently applied) is a specific analysis of generic estimates of observable and unobservable conditions.

Both tools have their respective strengths and weaknesses. There are reasons to believe that quantification of risk through reliability would logically include a quantification of inspection information. Application of risk analysis and CIs within the Corps has been at less than full potential due to limited historical data and limited knowledge and guidance of how best to apply them. With appropriate research and continued application and experience, their apparent benefits can be developed to full potential. Note that the Embankment Dam CI does have a more direct relationship to risk and reliability than other CIs. It considers current risk analysis knowledge on a relative scale.

5 CI Relation to Other Project Inspections

CW projects are inspected frequently and in many different ways. Not all inspections are thorough or comprehensive, but they do all contribute to knowledge about the project. Listed below are some common inspection types with brief explanations. Some special purpose inspections are not listed because this list is intended to focus on general inspection types.

Operational inspection – During operation of a project, personnel are usually able to detect obvious indications of local failures (sand boil, loss of miter) or changes in project performance (noise, vibration, increased leakage, crack growth). These observations are very important in the safe and continued operation of the projects.

Annual inspection – Most projects are inspected annually by project, area office, and/or District personnel. Details of these inspections vary between Districts. These inspections are much less detailed than Periodic Inspections but usually result in a short summary report. A common objective is to identify and prioritize maintenance needs for the budget cycle. They may result in an engineering inspection related to particular concerns.

Periodic Inspection – Periodic Inspections generally occur on a 5-year cycle. They include site visits to the project by representatives of all applicable engineering disciplines. Usually, the site visits include little investigation beyond an informal visual inspection. The inspection is not intended to discover unknown problems. Instead, it is an excellent opportunity to communicate known concerns with the various disciplines and discuss the significance any problems present at the project. The Periodic Inspection Report is a very important product. It provides a descriptive and pictorial review of the project's condition. Along with the memories of senior personnel, it serves as the primary record of historical condition. It also serves as a record of suggested actions such as further analysis (results may be included in the Periodic Inspection Report) or MR&R.

Fracture critical members inspection – Corps policy mandates that all fracture critical hydraulic steel structures be inspected at least once every 5 years for fatigue cracks. These inspections may be performed in conjunction with other inspections.

Engineering inspection – This can occur as a result of concerns by project personnel. An engineering analysis may be performed to determine if repairs are needed. An engineering analysis may also be recommended as a result of a Periodic Inspection. The results are usually included in the Periodic Inspection documentation.

CI Inspection Role

The inspections previously listed have reasonably clear roles in the O&M of CW projects, but there are some areas of weakness:

- They do not include any procedures for investigating the condition of steel structures, with the possible exception of fracture inspection.
- The procedures for completing the inspections are not rigorously defined and that reduces consistency across Districts.
- With the exception of some engineering inspections and analyses, the evaluations of condition are very descriptive. Without quantification, it can be difficult to compare current and historical condition documented in Periodic Inspections.
- The guidance for completing these inspections provides little or no assistance in achieving understanding of areas of concern. The guidance does not help the inspector understand the problems. It must be evaluated based totally upon his/her experience and knowledge. The guidance includes no preset standards for comparison.

All these areas are relative strengths of CIs. CI inspections clearly complement existing Corps' inspections and should provide significant long-term benefits.

CIs and Periodic Inspections

Periodic Inspections provide an extensive record of historical condition. There are at least three ways that CIs supplement and complement the Periodic Inspection process.

1. The Periodic Inspection Report is a detailed descriptive record of condition. With no quantification, it can sometimes be very difficult to review previous reports and determine whether the condition is improving or deteriorating.
2. The Periodic Inspection is not an investigation to uncover new problems. It is a process through which project personnel may provide additional information on known problems or from which more detailed studies may result, but the Periodic Inspection is mostly a record of known conditions.

3. The Periodic Inspection Report is the basis for many M&R activities at projects. As a subjective, descriptive report, it is often inadequate for convincing management of the need to expend funds. CIs provide quantified information that has been arrived at through a standardized process. This approach often proves to be more convincing than subjective explanations.

6 Technology Transfer Requirements

Current Guidance on CI Implementation

As stated previously, CIs were developed with the intent that they would be used to assist in the prioritization and justification of the nonrecurring work packages in the O&M budget. CI implementation has involved both training and policy initiatives. The first significant effort to establish policy on the use of CIs in CW occurred in 1991. This effort was a white paper developed by James Crews and John Elmore on "Initiatives in Decision Support Tools for Operations and Management" (Appendix H). This paper looked at both CIs and Quadrant and how they could be used along with the rest of the available and emerging O&M management tools, including reliability criteria for major rehabilitation projects. The second significant effort was a letter signed by Elmore, Subject: "Implementation of Condition Indices for the FY94 Budget and Beyond" (Appendix I). This letter states simply that, starting with the FY94 budget year, CIs will become routine submittal requirements for O&M work packages. So starting with the 1994 budget, all Engineer Circulars on the Civil Works Direct Program, Program Development Guidance contained a section on the utilization of CIs in the O&M budget development process. The following is the CI-related section in EC 11-2-177, 31 March 1999.

C-2.9. **Condition Indices (CI's)**

a. CI's are an important management tool that, coupled with other decision-making criteria, can help to optimize the effective use of limited resources. CI's are numerical indicators of the condition of equipment and structures that provide a quantitative and consistent means of describing their condition. They will enhance our ability to establish priorities and to justify maintenance requirements. Further information on CI's, and their relationship to maintenance management systems in general, can be found in various publications issued in connection with the Repair Evaluation, Maintenance and Rehabilitation (REMR) Research Program.

b. Technical notes are available from the Waterways Experiment Station that explain the procedures for determining CI's on structures for which

a CI methodology has been developed. Copies of these publications may be obtained from CEWS-SC-A.

c. CI procedures are being developed at the individual component level, (e.g., a miter lock gate, steel sheet pile structure, etc.). This generally lends itself to the work packages used to describe maintenance requirements in the Windows - Automated Program System (WINABS). Therefore, a CI should be entered for each work package record for which a CI procedure has been developed in the following Work Category Codes:

	WCC	Description
(1)	61110	Lock and Saltwater Control Structure Maintenance
(2)	61110	Breakwater, Jetty, and Seawall Maintenance
(3)	613N0	Power Plant Maintenance (Use of CIs is not required for hydropower work packages funded under the Bonneville Power Appropriation)

Current Utilization of CIs by Civil Works

In the spring of 1997, CERL conducted a telephone survey of CI utilization at Corps CW Districts. The objective of the survey was to determine how many Districts were aware of the CI tools, how many Districts were actually using the CI systems, which systems were being used, and how and why were the systems used. The initial District point of contact (POC) for the survey was generally the Chief of Operations (or Con/Ops). Appendix J summarizes the findings of the survey, including a list of what Districts liked and disliked about the CIs. The table indicates that approximately two-thirds of the Districts have used the CIs in some way, but of that number only about one-third of the CI usage consistently followed the procedures as they were developed. The major dislike of the CI systems was that they were perceived to require too much time, money, and personnel to accomplish.

Following the telephone survey, site visits were made to various District and area offices to better understand why and how the CI systems were or were not being used. Additionally, at Districts that had either inland navigation or hydropower facilities, the enquiry expanded to include Quadrant utilization. Districts that were visited included: Rock Island, Chicago, Portland, and Nashville.

In addition, the Peoria (Rock Island) and Grand Haven (Detroit) Area Offices were visited. The visits focused on discussions with Operations, Engineering, and Programming personnel. The discussions centered on how each District prepared and prioritized their O&M budget, including the use of CIs. Also, if CIs were used, the methods of obtaining CI ratings were discussed. Based on these site visits, CERL prepared a short paper (see Appendix K) that summarized the findings and made specific recommendations for improving CI and Quadrant utilization. The conclusions from the site visits indicated that, although some Districts felt CI inspections were useful tools for determining M&R needs, they do not believe that CI and/or Quadrant information is critical to their prioritization of District maintenance activities. They also believe that the use of CIs/Quadrant has no effect on O&M funding for a District. These concerns are additional to the time and cost issues listed in the telephone survey.

Additional Required Policy Initiatives

The earlier Engineer Circular policy statement is a good example of a well intended initiative that was not adequately thought through. It states in subparagraph c of section C-2.9, for example, that CIs are developed at the individual component level, thus lending themselves to the work packages used to describe maintenance requirements of WINABS. The study by CERL on the above WCCs in ABS, however, indicated that only 20 percent of the sample work packages directly relate to an existing CI. An additional 20 percent could be related to a composite of existing CIs. The remaining work packages need additional CIs and/or policies to apply a CI when all the work is not defined within the current CI system.

Guidance is also lacking in the area of CI inspection frequency. There is currently no guidance in this area. Ideally, each annual O&M budget cycle should use current CI data. The simplest way to achieve this is to do a CI inspection of all CW infrastructure annually, but complete annual CI inspections would be cost prohibitive and not necessary to achieve the intended objective of a snapshot of the condition of the work package being proposed. It would be preferable to perform CI inspections for components included in work packages and for all components at a less frequent interval. What is needed is a policy that looks both at the complete CI inspection requirement and integrates it with other CW inspection requirements to assure optimum efficiency and effectiveness of the inspection effort.

In addition to the lack of guidance for direct CI implementation, no procedures are in place for continued training or direct field support, including upgrade and support of software requirements.

Although no official policy to date requires it, some Districts already make CI inspections to coincide with, and be executed just prior to, the Periodic Inspections. The CI data should be included in the pre-inspection brochure, and included as part of the permanent record in the Periodic Inspection Report.

Appendix K includes a summary of potential solutions to the overall technical transfer/implementation problem. This position paper was developed in 1998, but the problems and solutions have not changed significantly since that time.

7 Research Initiatives and Possibilities

Additional CI Development

CIs have been completed for most of the common infrastructure components under funding through the REMR research program. Appendix E shows both completed indexes and the most common structural components that do not have a CI.

Work under the REMR program (1984 – 1998) did not include any CIs in the recreation business area. Some CIs applicable to recreation infrastructure have been completed at CERL under both direct and reimbursable military funding. The PAVER CI is the oldest and most fully developed CI system. The PAVER EMS includes a rigorously developed system for work prioritization based on minimization of MR&R costs. This is significantly different than the CW focus on prioritization based on minimizing direct customer costs. EMS systems for buildings and various utilities have also been worked on and are in various stages of completion.

Another system for infrastructure assessment — the Installation Status Report (ISR) — has been developed for military use. The ISR is nearing full implementation on military installations. The status rating is based on subjective descriptions of condition and functionality delineated in three levels. These levels are associated with the colors green, yellow, and red to indicate the readiness of the building and its site. This system provides very little detail on specific buildings but, when looking at an installation or a Major Army Command (MACOM), it may be a good indicator of overall readiness. Although ISR may be beneficial for system-level planning, it lacks adequate detail for work-level prioritization. A large improvement could easily be made in ISR without significantly increasing the implementation effort, by making separate ratings of functional adequacy and condition. An example of functional inadequacy would be to use a 300-ft lock to pass through a large number of 1200-ft tows. Improvement in ISR effectiveness could also be achieved by using a more detailed algorithm to combine the component ratings for a building site.

Further CI development will be funded under the "Management Tools for O&M" research program, but it is unlikely that a CI as we know it will be developed for

every component of CW projects. It is important that most common types of CIs be reverified and development of further CIs be prioritized. Less common structural types may have no CI, or an abbreviated rating method similar to ISR could be developed for them.

Management Tools for the O&M Program

The O&M program started in FY2000. Documentation of this program is included in Appendices B and C. In addition, many of its objectives are discussed throughout this report. Briefly, the objectives of the program include further development of CIs, the development of composite CIs for O&M work packages, the development of SIs for assessing and tracking project condition, and the development of a method to quantify the dollar-based or relative priority of ABS work packages. In addition to the CI and work package prioritization efforts, the program has an O&M Cost Reduction Handbook initiative.

The O&M Management Tools Program was originally conceived as a tool to assist CW in meeting the objectives of the Government Performance and Results Act (GPRA) and the Corps *Performance Measurement Guidebook* (1995). The original proposal focused on a performance-based O&M budget prioritization process. It was briefed to HQUSACE in 1996. Based on feedback, the proposal was modified to assure proper focus and was presented in March 1997 to a HQUSACE review group. The review group supported the concept of developing SIs that are functionally based, weighted roll-ups of the existing REMR CIs. Additionally, the review group recommended that CIs be expanded and additional Quadrants be developed for other business functions for operating projects. They concurred in the need for the additional tools and supported moving ahead with the proposal to the CW R&D Committee and funding starting in FY99. A detailed proposal (Appendix C) and a Congressional justification sheet were prepared for an FY99 program start. An initial field review group (FRG) meeting was held in May 1998 (Appendix G). The FRG supported completing and simplifying the CIs, the tying of CIs directly to Quadrant, and the expansion of Quadrant to other business areas. The FRG did not, however, support the need for SIs. Between the May 1998 and November 1999 FRG meetings, several other meetings were held that predominately related to problems with the Quadrant cost/benefit model. Minutes of two meetings, June 1998 and March 1999, are also part of Appendix G. In summary, specific additional work on Quadrant was halted until an overall assessment of various other options for work package prioritization can be assessed.

In addition to re-examining the viability of the Quadrant program, several other leadership issues have focused attention on the overall O&M Management Tools Program. These activities include a commitment from USACE senior leaders to grow or right size the CW O&M program. Presentations at the 1998 and 1999 Senior Leaders Conference by Charles Hess, CECW-O, focused attention on the need to identify and prioritize O&M funding requirements. In addition the O&M Top 10 + 1 developed by the Corps Divisions' Chiefs of Operations (Appendix L) indicate command support for the initiatives proposed in the O&M Management Tools Program.

The O&M Management Tools Program also is responsive to the field concerns that were uncovered during the telephone survey and the District site visits. The emphasis on simplifying CI inspections, for example, is a response to the cost and effort required for CI inspections, as defined in the telephone survey described in Chapter 6.

An O&M Management Tools Program FRG meeting was held in November 1999. This meeting was not scheduled until USACE was assured that the program had FY00 funding. The meeting minutes (Appendix G) indicate a high level of support for the overall program. A second FRG meeting was held in August 2000. The meeting minutes are in Appendix G.

The 3-year research effort is comprised of the following four work units:

Simplified CI Inspection Procedures Work Unit

The focus of this work unit is (1) simplification of CI inspection procedures, (2) completion of existing CI documents, (3) enhancements (or needed revisions), and (4) new starts. The primary objective of the simplified CI work unit is to investigate inspection methods requiring 20 to 50 percent of the current effort while maintaining 80 percent of the original integrity. This is a flexible target and the most effective simplification will be developed for each component CI (see **CI Simplification** in Chapter 2). The Army ISR system of red, yellow, and green needs to be considered as a potential simplification, particularly for new CIs.

Summary Index Work Unit

The focus of this work unit is to develop an index for physical and functional condition of a project or site. The work will include the composite CI required for the O&M work packages in ABS and build to a project level SI. The project level SIs can be used to track overall project health and the relation between funded maintenance activities and condition over time.

Benefits Analysis Work Unit

This work unit focuses on quantifying M&R benefits for work package prioritization and budget defense. The initial effort is to look at the various prioritization schemes that have been or are being proposed and recommend a path for O&M to take. The November 1999 FRG meeting emphasized supporting the current division-led effort on multi-attribute prioritization schemes for the O&M budget. CERL continues to support Division-led prioritization efforts.

O&M Cost Reduction Handbook Work Unit

This Internet-accessible electronic handbook will provide CW Districts with easy access to field-validated best practices that have been developed by the laboratories in support of O&M.

Risk Analysis for Dam Safety Program

This program has the single objective of developing a formal risk-based process for justification and prioritization of large dam safety expenditures. It includes portfolio assessment, analysis of probabilities of failure, determination of consequences, and an economic analysis. The field review committee has determined that the use of CIs should be considered. Study for the electrical/mechanical and gates work unit includes looking at how CIs can be used to improve the reliability estimates. Although not specifically funded, the embankment CI or a new process modeled on that CI could be useful in the portfolio assessment process.

8 Summary

CIs are quantitative ratings between 0 and 100 that estimate the physical condition, as a snapshot in time, of a structure or structural component. They were originally developed to assess condition with the intent that this information could be used to assist in the prioritization and justification of the O&M budget. This document briefly describes how CIs were developed, what they historically were intended to accomplish, a listing of other current and potential benefits in CI utilization, and an assessment of current policy relative to CI utilization. A review of the current but limited utilization of CIs is presented along with a list of common CI perceptions and misperceptions, and a list of specific examples where CI data has been successfully used to assist Districts in solving a variety of problems. The relationship between CIs and other business and research initiatives is also explored. In this area, specific attention is given to the CIs as they relate to O&M budget work packages and ABS. Also discussed is using CIs as a tool for risk and reliability initiatives.

In conclusion, a number of issues seem to be of primary concern:

- It is obvious that CIs are not widely used by Corps Districts or Divisions for prioritizing O&M work packages even though they have been a requirement of ABS in selected work categories. Decision support tools (that may or may not include CIs) are needed to support the O&M budgeting process.
- Several Districts have used CIs as benchmarks of physical condition and to assist in other issues. One of the primary misperceptions is that CIs are cost prohibitive, but recent work by Rock Island District indicates that CIs do not have to be cost intensive.
- The assessment of policy issues relative to CI implementation, including the use of CIs in the ABS system, indicated both a significant policy shortfall and obstacles to following the limited guidance. In particular, the existing CIs are inadequate to rate the overall condition of the structure(s), component(s), subcomponent(s), etc. within most individual O&M budget work packages.
- CIs may be able to provide assistance to a variety of risk and reliability initiatives that are currently under development, including both areas of major rehabilitation and dam safety.

Work units in the O&M Management Tools Program have been laid out to address a variety of the stated issues and shortfalls relative to CIs:

1. The CI Simplification work unit within the program will simplify existing CI inspection procedures and complete new simplified CIs to fill the CI gaps such that O&M work packages can be represented by a composite CI.
2. The Summary Index work unit will develop rules for developing composite CIs to represent O&M work packages and SI to represent the overall condition of a CW project site.
3. The Benefits Analysis work unit will focus on quantifying M&R benefits for work package prioritization and budget defense.

The primary overall objective of the O&M Management Tools Program is to develop an objective condition-based/benefit analysis system to assist Corps CW O&M managers in identifying and prioritizing O&M funding requirements for nonrecurring maintenance activities. This benefits analysis should identify minimum O&M requirements and quantify the impacts of budget changes, including deferred maintenance. A fourth objective of the program is not directly related to CIs.

The Risk Analysis for Dam Safety Program within the electrical/mechanical and gate work unit is the first attempt at using CIs to assist in a major risk analysis research program. This effort provides the opportunity to determine how CIs can be used to assist in risk analysis studies.

References

Ayyub, B.M., M.P. Kaminskiy, and D.A. Moser, "Reliability Analysis and Assessment of Hydropower Equipment," IWR technical report under contract USDA-CSRS-95-COOP-2-1792, April 1996.

U.S. Army Corps of Engineers National Operation and Maintenance Program: Performance Measurement Guidebook, prepared by The Operations and Maintenance Plan of Improvement Task Force for Performance Measurement and Data Management, prepared for the Operations, Construction, and Readiness Division, Directorate of Civil Works, U.S. Army Corps of Engineers, Washington, DC, 1995.

Dijkstra, O.D., "Probablistic Maintenance Planning for the Tubular Joints in the Steel Gates in the Eastern Scheldt Storm Surge Barrier," *Proceedings of the Sixth (1996) - International Offshore and Polar Engineering Conference*, Los Angeles, May 1996.

Estes, A.C., and D.M. Frangopol, "Repair Optimization of Highway Bridges Using System Reliability Approach," *ASCE Structures Journal*, July 1999, p 766.

Mlaker, P.F., "Reliability of Hydropower Equipment," Submitted to WES under contract DACW39-93-0073, April 1994.

Russell, C.S., R. Magda, T. Feather, J.F. Langowski, P. Ventikos, E.M. Pettit, "Quadrant: Incremental Analysis Methodology for Prioritizing O&M Projects (Lock and Dams) Report," contractor report submitted to Institute for Water Resources, February 1993.

Appendix A: FY 1999 Proposal

Implementation Issues and Strategy for Condition Indexes and Quadrant

Sponsor: Harold Tohlen, CECW-O, 202-761-1713, Fax 202-761-1779

PI: David McKay, 217-352-6511, x7375, FAX 217-373-7222

Co-PI: Stuart Foltz, 217-352-6511, x7301, FAX 217-373-7222

1. Background: A set of condition indexes (CIs) has been developed by CERL for CECW-O. These CIs are objective measures of physical condition based on standardized inspection procedures.

2. Reference: Reference meeting at Institute for Water Resources on 9 January 1999 between Paul Howdyshell CECER-FL-P, Harold Tohlen CECW-OM, Robert Daniel CECW-PD, Michael Krouse CEWRC-IWR-R, James Comiskey CEWRC-IWR-A, and other IWR participants.

3. Problems:

- CI inspection information is useful for identifying repair requirements but it is unclear how to use the condition index ratings in local (site specific) and network (District, Division and Headquarters) budget prioritizations and justifications.
- The CIs are currently being used by some Corps Districts but not by others. This reduces benefits the Corps gains from CIs and does not allow network level evaluation.
- The Corps has other inspections that may collect some of the same information as CIs or may benefit from some of the CI information. Duplicative tasks are inefficient and need to be coordinated.

4. Objectives: For the Corps to maximize utilization of the CIs, it is necessary to determine and communicate the uses and benefits of CIs to Corps Districts, Divisions and Headquarters.

5. Approach:

TASK 1: CERL will discuss the roles of CIs at project, district, division, and headquarters levels with representatives from each group. This will be accomplished through telephone surveys, interviews and workshops. The focus will be to identify an implementation strategy that assures proper use of CI/Quadrant with respect to field and HQ concerns. The following issues shall be considered and resolved or a strategy planned to the degree possible:

- Identify conflicts and overlaps between CIs and various inspections, safety programs, and maintenance requirements. Document how CI/QUADRANT can augment same.
- Enumerate benefits that can be obtained today with current CI/QUADRANT applications and level of implementation. Also cite benefits that might result from development of new CIs or other CI applications. Enumerate benefits that might result if CIs were implemented uniformly on National level.
- Dispel flawed perceptions (in writing) of CI/QUADRANT costing too much, taking too much time, or providing otherwise useless information.
- Identify specific results that have benefited Districts using CI/QUADRANT.
- Document current uses of CI/Quadrant systems within the Corps as they exist today.

TASK 2: Support IWR in their effort to establish relationships between QUADRANT, CI, and Reliability Analysis by hosting a visit by Michael Krouse, CEWRC-IWR-R.

TASK 3: Review ABS database for maintenance packages near the cut-off for prioritizing remaining CI requirements.

TASK 4: Write a report to document information gathered during this project. The report will also propose a CI/Quadrant utilization strategy that addresses both lessons learned and incorrect perceptions.

6. Sponsor's Role: The sponsor will participate in discussions on the uses of CIs.

7. Products: The product of this effort will be a written report. The report will review information gathered during the project and the recommendations that resulted based on that information.

8. Milestones:

	Time After Receipt of Funds
• Interviews, Meetings, Workshops	30JUN99
• Meeting with IWR re Reliability, CI and QUADRANT	30MAY99
• CI impact on M&R backlog analyses	31JUL99
• Draft Final Report	31JUL99
• Final Report to CECW-O	30SEP99

9. Cost Estimate: The cost of this proposal is listed below by tasks as described in Paragraph 5.

- Task 1 - $14,140
- Task 2 - $5,280
- Task 3 - $2,112
- Task 4 - $7,040
- Admin, Travel, Misc - $16,500

- $50K total

10. Completion: This project shall be completed by 30SEP99.

11. Technology Transfer: This project is to develop a technology transfer plan. It is being conducted in coordination with IWR, CECW-O, CECW-E, CECW-P, Division and District representatives. The results will be incorporated in a report explaining the investigation and outlining the plan.

We, the undersigned, agree to the terms of this proposal.

______________________ ______________________

Sponsor Signature PI Signature

Management Chain: The following names and office symbols are offered to keep the sponsor appraised of the above PI's management chain. The DC is the immediate supervisor, and the LOC is the DC's supervisor.

Division Chief (DC): Simon S. Kim Office Symbol: CECER-FL-P

Lab Operations Chief (LOC): Michael Golish Office Symbol: CECER-PL

Please return the signed proposal with the funding documents to:

CERL
ATTN: CECER-RM (Roy Roberts)
P.O. Box 9005
Champaign, IL 61826-9005

COMM 217-373-6797
FAX 217-373-6707

The signatures on this page of the sponsor and the PI certify agreement that the proposed work is technically sufficient but they do not obligate either party to expenditure of funds or expenditure of resources to execute the work. To achieve commitment of funding or resources, all work must be further approved by the CERL Director and the sponsor's obligation authority.

Appendix B: Congressional Justification Sheets for the FY01 and FY00 O&M Management Tools Program

APPROPRIATION TITLE: Operation and Maintenance, General -- FY2001

1. PROJECT OPERATIONS SUPPORT PROGRAM

Management Tools for O&M

SUMMARIZED FINANCIAL DATA

Estimated Total (FY 2000-2002) Program Cost	$2,265,000
Allocation for FY 2000	500,000
Allocation Requested for FY2001	1,100,000
Balance to Complete after FY2001	665,000

JUSTIFICATION: Operations and Maintenance, General is the Corps of Engineers largest Civil Works (CW) appropriation account. During preparation of the budget for submittal to the Office of Management and Budget (OMB) and Congress, managers of the CW Operation and Maintenance (O&M) appropriation must identify, provide cost estimates for, and assign priorities to the work to be accomplished and/or deferred in the program for the budget year. The prioritization requirement is complicated by the diversity (five uniquely different major business areas) and size of the CW O&M budget. Because the funding needs significantly outstrip the available programmed funds, an objective and consistent prioritization process is essential. Typically, the CW O&M budget contains over 17,000 items of work on approximately 850 projects in 38 Civil Works districts throughout the nation. Recent appropriation levels have included moderate growth in the CW O&M budget from approximately $1.6 billion in fiscal year 1998 to an estimated $1.88 billion in fiscal year 2000. Budget caps and other restraints will make future O&M budget increases more difficult to obtain even though O&M requirements will increase. Thus, the CW O&M budget constraints and the requirement that the budget be performance based are the impetus for this research program. It proposes a performance-based benefits analysis model/procedure for prioritization/ranking of the maintenance activities of the annual Civil Works O&M budget and it includes a best practices component to assist in cost efficient execution of the O&M budget.

The need for a performance-based benefits analysis procedure has been validated by several recent policy initiatives including: The Government Performance and Results Act (1993), and the Corps' Performance Measurement Guidebook (1995). The product of this research will provide an objective, consistent, and reproducible procedure, to be used for both O&M budget prioritization and quantifying the impact of deferred maintenance on maintenance and/or operations expenditures. The product can also be used to identify the optimum (lowest) level of O&M funding required to maintain justified and established levels of customer service. It accomplishes this by relating maintenance expenditures to condition changes, and condition changes to changes in customer service and/or operation/maintenance expenditures.

The best practices effort is needed to assure that lessons learned in technology and process application at one district is shared with all districts and project sites. The product, an Internet accessible, O&M Cost Reduction Handbook, will provide brief descriptions of research activities that have been successfully utilized in the field but not widely implemented. The Handbook will initially focus on CW O&M funded research that has been successfully used in the field by at least one district.

Limited work required to develop a performance-based benefit analysis model for O&M budget prioritization has already been initiated by previous or other ongoing activities. The completed work includes the component level condition indices (CIs) and QUADRANT. The CIs are objectively based, reproducible numerical indicators of the condition of structures and equipment. CIs are developed at the component level (e.g., lock gates, dam gates, concrete monoliths, steel sheet pile structures, etc.). CIs have been completed for all CW infrastructure excluding recreation facilities, levees, lift gates, and electrical/mechanical motors. QUADRANT is a management tool for providing economic (net benefit value) information for prioritizing annual non-routine maintenance. QUADRANT has been prototyped and evaluated for inland navigation and hydropower, and significant modifications identified. The ongoing work includes several multi-attribute prioritization efforts, and models for maintenance optimization. The missing items required to complete the performance-based benefit analysis model are the completion of the remaining CIs, the development of composite CIs for O&M work items, and the development of an objective and consistent benefits analysis model. A summary Index (SI) procedure, based on CIs, will be developed for indicating the overall condition of a project or site. Additionally, a recent analysis of CIs and QUADRANT use indicates that the final product must be simple and easy to use. Thus the CI inspection procedures will be revised and simplified, and the performance based benefit analysis model will be simple and user friendly.

FY2001 ACTIVITIES: Field utilization of the O&M Cost Reduction Handbook will be assessed to determine the required modification including the need for a feedback loop. Based on the FY00 analysis the development of simplified CIs will be initiated to support the composite CI requirement. Also new CIs will be developed to support the composite CI requirement. Development of SIs for site or project condition indices will be initiated. The development of a benefits analysis procedure for O&M budget prioritization will be initiated, and it will integrate the FY00 field effort.

FY2000 ACCOMPLISHMENTS: The beta version of the O&M Cost Reduction Handbook was completed and field evaluation initiated. Reports and training were completed on the Embankment Dam and Non Rubble Breakwaters & Jetties CI procedures. Decision points were reached on what other CIs will be developed, and how CI inspection procedures will be simplified. Procedures for developing composite CIs that are applicable to maintenance work items in the annual O&M budget were proposed for field review. A review of existing methods of benefits analysis for work item prioritization was completed and integrated into ongoing field efforts directed at O&M budget prioritization.

Appendix C: Detailed Proposal for O&M Management Tools Program

July 1997

MANAGEMENT TOOLS FOR CIVIL WORKS

PROJECT PROPOSAL

1. PURPOSE

The purpose of this document is to present a research proposal to support the new research and development (R&D) initiative on Management Tools for Civil Works. The focus of this document will be a suite of decision support tools for improved development/articulation/justification of the Civil Works Operations and Maintenance (O&M) Budget.

2. BACKGROUND

In the 1980s Civil Works initiated several decision support and automation efforts to assist in the quantification and standardization of the O&M budget prioritization process. These efforts included the Automated Budget System (ABS), REMR-developed component Condition Index (CI) system, Navigation-QUADRANT (NAV-QUAD), and Hydropower-QUADRANT (HYDRO-QUAD). Related efforts for major rehabilitation projects developed during this time period included risk-based benefit cost analysis and reliability indices.

The ABS is essential to handle the identification, cost estimates, and prioritization of an O&M annual budget that routinely contains 17,000 packages of work on approximately 850 projects in the 38 Civil Works Districts. The CIs are objective-based, reproducible numerical indicators of the condition of structures and equipment. CIs are developed at the component level (e.g., miter lock gate, steel sheet piling structures, etc.), and are a part of the ABS work package justification requirement. QUADRANT is a management tool for providing economic (net benefit value) information for prioritizing annual non-routine maintenance. It directly ties maintenance activities to performance, and can facilitate the optimization of the limited O&M funds.

The development work on the ABS and most of the REMR CI system is complete. QUADRANT has been completed for inland navigation and is nearly complete for hydropower. The major missing item is an objective and reproducible procedure to produce summary indexes (SIs) for use in NAV-QUAD and HYDRO-QUAD systems. In the remaining Civil Works business areas both QUADRANT and SIs are required. SIs are functionally based, weighted roll-ups of the CIs and are required for cost benefit analysis. For QUADRANT to be effective in the prioritization of the O&M work packages, the SIs must be objective, weighted roll-ups of the component CIs from the REMR Operations Management program.

Both the Government Performance and Results Act (GPRA) of 1993 and the Corps' Performance Measurement Guidebook (August 1995) emphasize the need for a performance based O&M budget prioritization process. The Construction Engineering Research Laboratory (CERL) with support from the Institute of Water Resources (IWR) and Hydroelectric Design Center (HDC) developed a proposal for a Performance Management Support System. This proposal was initially presented to HQUSACE in the summer of 1996. Based on feedback, the proposal was modified to assure proper focus and was represented in March 1997 to a HQUSACE review group. The review group included personnel from Engineering Division; Planning Division; and Operations, Construction and Readiness Division, Civil Works Directorate. They supported the concept of developing SIs that are function-based, weighted, roll-ups of the existing REMR CIs. Additionally the HQUSACE review group recommended that CIs need to be expanded along with additional QUADRANTs for other business functions for operating projects. They concurred in the need for the additional tools and supported moving ahead with the proposal to the Civil Works R&D Committee.

3. OBJECTIVES

The objective is to develop a performance-based return-on-investment (ROI) model/procedure to support an objective prioritization/ranking of the work packages in the annual Civil Works O&M budget. Figure 1* depicts a schematic of the performance-based O&M investment model. The model/procedures will be developed for each Civil Works business area. The performance criteria for the model/procedure will be varied depending on the business area and the specific beneficiary of the proposed work. The process will also address minimizing project and district resources required for data input.

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* Figure 1 is not included in this report.

4. APPROACH

The proposed efforts will build on the previously-developed REMR CIs, QUADRANT and ABS. The approach is: (1) to complete the development and testing of the SIs as required by QUADRANT for each Civil Works business area (inland navigation, coastal navigation, flood control, hydropower, and recreation); (2) develop QUADRANT-like cost-benefit models for the coastal navigation, flood control, and recreation business areas; (3) deploy and field the performance-based ROI model/procedure (CIs/SIs/QUADRANT) for O&M work package prioritization.

In addition to the above, inspection procedures and inspection techniques for CIs need to be reassessed. Techniques to reduce the field resource required for inspections that are consistent with the CI requirements of objectivity/reproducibility need to be developed.

The work is intended to be a collaborative effort between CERL, IWR, HDC, and HQUSACE, with expert Division and District input, as needed. This development team will form a Study Advisory Group, representing the participating organizations, to guide and monitor the effort.

The major tasks are:

1. The development of SIs for each Civil Works business area (inland navigation, coastal navigation, flood control, hydropower, and recreation).*

    a. Complete component condition indexes if they are not yet completed and are a major repair component required for a roll-up in a SI.

    b. From the existing CIs, develop algorithms for producing appropriately weighted SIs which are functionally based and indicate the performance (or threatened loss of performance) for a complete feature or project. As appropriate, incorporate risk/reliability models.

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* SIs for inland navigation and coastal navigation are scheduled for development in the FY98 REMR Operations Management Program if the program is fully funded.

2. Develop QUADRANT-like cost-benefit models and complete interface with CI/SI system for the coastal navigation, flood control, and recreation business areas and complete interface with CI/SI system for the existing NAV-QUAD and HYDRO-QUADRANT.

    a. Develop interface between CIs and QUADRANT, so that SIs are fed directly into the QUADRANT programs.

    b. Develop version of QUADRANT for coastal navigation, flood control, and recreation business areas.

    c. Develop output in required ABS format.

3. Methods to minimize input (CI) data requirements.

    a. Develop methods to more easily collect required condition and function information needed to produce condition indexes.

    b. Develop methods to transfer component condition and functional information directly from the field site into the management computer program to minimize manual recording in the field and re-keying information into the program in the office.

4. Deploy and field the ROI model/procedure (CIs/SIs/QUADRANT) for O&M work package prioritization.

    a. Test prototype system at selected sites.

    b. Refine system, as suggested by tests, and evaluate its capabilities.

    c. Submit initial system, with report describing its functions and capabilities.

5. PRODUCT

A performance-based O & M work package prioritization/ranking computer system for each business area, along with field procedures to provide the necessary input. Each completed system will include inter-operating components: (1) CI subsystem, (2) SI subsystem, (3) QUADRANT.

6. BENEFITS

The primary benefits of this Research Program include:

a. Performance (net benefit value) based prioritization for O&M work package ranking in compliance with EC 11-2-172 and GPRA.

b. Consistent and objective procedure for O&M budget justification and prioritization.

c. Ability to quantify the impacts of reductions or increases in recommended funding levels.

d. A mechanism to assist in the assurance of a uniform level of service within and between business functions for available O&M funding.

e. Condition versus performance benefit data that can be used to assist in the planning and engineering of major rehabilitation requirements.

7. SCHEDULE

Task #	Task Description	Completion Date
1	Development and Testing of SIs Inland Navigation: Test SI Coastal Navigation: Test SI Flood Control: Develop and Test SI Hydropower: Develop and Test SI Recreation: Develop and Test SI	 3rd Q FY99 3rd Q FY99 4th Q FY00 2nd Q FY00 4th Q FY00
2	Develop Quadrant like Cost-benefit Models Inland Navigation: Improvements Coastal Navigation: Develop Flood Control: Develop Hydropower: Improvements Recreation: Develop	 2nd Q FY00 2nd Q FY01 2nd Q FY00 2nd Q FY01
3	Develop Methods to Minimize Input (CI) Data Requirements	2nd Q FY01
4	Deploy and Field the ROI Model/procedure (CIs/SIs/QUADRANT) for O&M Work Package Prioritization Inland Navigation: Field Test and Deploy Coastal Navigation: Field Test and Deploy Flood Control: Field Test and Deploy Hydropower: Field Test and Deploy Recreation: Field Test and Deploy	 2nd Q FY01 4th Q FY01 4th Q FY01 2nd Q FY01 4th Q FY01

8. COST ESTIMATE ($ 000)

Task		FY 99	FY 00	FY 01	TOTAL
1	Development and Testing of SIs*				
	Inland Navigation: Test SI	50			50
	Coastal Navigation: Test SI	75			75
	Flood Control: Develop and Test SI	75	160		235
	Hydropower: Develop and Test SI	150	60		210
	Recreation: Develop and Test SI	100	160		260
2	Develop Quadrant like Cost-benefit Models				
	Inland Navigation: Improvements				
	Coastal Navigation: Develop	50	50		100
	Flood Control: Develop				
	Hydropower: Improvements		160	50	210
	Recreation: Develop	50	75		125
			160	50	210
3	Develop Methods to Minimize Input (CI) Data Requirements	50	150	150	350
4	Deploy and Field the ROI Model/Procedure (CIs/SIs/QUADRANT) for O&M Work Package Prioritization				
	Inland Navigation: Field Test and Deploy			100	100
	Coastal Navigation: Field Test and Deploy				
	Flood Control: Field Test and Deploy			100	100
	Hydropower: Field Test and Deploy				
	Recreation: Field Test and Deploy			80	80
				80	80
				80	80
	Annual totals	600	975	690	2265

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* Cost estimates assume full funding for the REMR Operations Management Program. Any funding decrement will need to be carried over into this proposal if it occurs.

9. POINTS OF CONTACT

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Simon Kim, CERL	(217) 373-7269	(217) 373-6740
Paul Howdyshell, CERL	(217) 373-6762	(217) 373-7222
James Comiskey, IWR	(703) 428-9068	

Appendix D: Proposal for Probability of Failure of Gates, Equipment, and Warning Systems

Risk Analysis for Dam Safety research program – work unit description for: "Probability of Failure of Gates, Equipment, and Warning System"

PROGRAM	521 - Risk Analysis for Dam Safety	6/22/99
WORK UNIT #	33262	
WORK UNIT TITLE	Probability of Failure of Gates, Equipment, and Warning System	

PERFORMING LAB WES/CERL

PRINCIPAL INVESTIGATORS

Robert C. Patev, CEWES-ID-E 601-634-4453

Joseph A. Padula, CEWES-ID-E 601-634-4451

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ADDRESS 3909 Halls Ferry Road
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PROBLEM

The risks associated with potential failures of dam gates and valves at spillways and outlet works is heavily dependent on the overall performance of mechanical, electrical, and structural components. Generally, the performance of a gate system is impaired by means of one or a combination of the following conditions: unusual or excessive hydraulic loading during extreme flood events; degradation due to corrosion, wear, and fatigue; structural imperfections due to construction error, inadequate design/application, and change of operating conditions; operational failure of the gate mechanism (e.g., misalignment, lack of proper lubrication, operator/PLC error and other detrimental conditions often induced by lack

of proper maintenance); and functional failure of the driving electrical/mechanical equipment.

These components must perform successfully to maintain the reservoir's capability to control the discharges under normal, unusual, and especially extreme events such as PMF. Potential problems have been encountered on spillway systems during critical events. Failures at Folsom Dam and Red Rock Dam are two recent examples. In addition, with an overall decrease in Federal funding to maintain these components, minimal maintenance and infrequent inspection of these components will occur which will increase the probability of gate and equipment failures especially during extreme events.

OBJECTIVE

The objectives of this work unit are to investigate and develop risk assessment methodologies and overall framework to determine and quantify the probability of gate, equipment, and warning systems failures and associated consequences during normal, unusual, and extreme events. These objectives will be accomplished through work efforts in the following areas: development of procedures for the identification of critical components and the evaluation of the probability of occurrence for critical events (event/fault trees) using Failure Mode Effects and Criticality Analysis; development of a screening risk assessment tool for gate systems to determine if further detailed reliability analysis is required; development of time-dependent reliability techniques to estimate the probability of failure of the associated driving electrical/mechanical equipment during extreme operating events; development of time-dependent reliability techniques for the probability of failure of gate systems in dams (Failure in this case is defined as a critical state of the gate subsystem condition such that the set of gates ceases to perform its intended function); informational survey of dam projects from the Corps of Engineers, Bureau of Reclamation, and other federal agencies to determine what type of warning systems and early-warning systems are currently in use, their operational successes/failures, and associated emergency plans.

DESCRIPTION

The potential failures of dam gates and valves at spillways and outlet works during extreme events involve a complex sequence of event combinations and potential failure modes. This work effort will provide research in the following areas: 1) Identification of critical operating equipment and definition of potential failure modes for gates, valves, and operating components; 2) Establish event/fault trees for the structural and operating components to be used in Failure Mode Effects and Criticality Analysis (FMECA). These component combinations will

require the incorporation of time-dependent aspects for both M/E and structural components; 3) Enhance current reliability techniques for M/E equipment in ETL 1110-2-549 to include load dependencies and system reliability concepts under extreme load events; 4) Perform reliability calibration of critical structural and operating components and investigate cross-correlation of reliability with Condition Indices; 5) Develop a screening risk assessment tool based on condition assessment to assist with investigating the need for further detailed reliability analysis; 6) Provide criteria for inspection and maintenance scenarios using both reliability analysis and condition index ratings; 7) Develop structural reliability models of spillway gate and outlet works components to assess the probability of failure of these components under various usual, unusual and extreme events; 8) Case studies will be selected to use in calibration of the risk assessment procedures and framework; 9) Develop technical guidance to assist District personnel in performing a spillway and outlet works risk assessment analysis for dam gates, equipment, and warning systems in use at existing dam projects. If necessary, incorporate risk-based evaluation of flood and warning preparedness systems recently developed into FMCA model; 10) Conduct an informational survey and investigate the comparison of current warning and early-warning systems and associated emergency plans in use at existing dam projects. If necessary, incorporate risk-based evaluation of flood and warning preparedness systems recently developed into FMCA model; 11) Development of interim guidance will be completed at steps during the program to document the progression of the research.

BENEFITS

The products from this research will provide a rational framework for the comprehensive evaluation of the probability of failure of a given dam gate system under usual, unusual and extreme flood events. The technology will be used in other research areas under the Risk Analysis for Dam Safety Program as well as in other risk assessment R&D programs underway in the Corps of Engineers. Technology transfer to Corps districts, other Federal agencies, and private industry will be through written reports, technical guidance, potential software development, and technical workshops.

ACCOMPLISHMENTS

Conducted a collaborative meeting on failure of gates and associated equipment with attendees from Corps' District/Division offices, Bureau of Reclamation, and HydroQuebec. Formed a COE Field Advisory Committee on this work unit from attendees at the collaborative meeting.

MILESTONES

TITLE	SCHED	RESCHD	COMP
Identification of critical operating equipment	0006		
Develop procedures for FMECA analysis	0006		
Perform research on CI/reliability correlation	0006		
Publish report on FMECA analysis	0009		
Complete survey for warning system study	0109		
Publish report on CI/Reliability correlation	0009		
Investigate enhanced reliability models for M/E equipment	0012		
Publish report on warning system study	0112		
Develop screening tool for prioritization	0112		
Develop interim guidance and recommendations	0112		
Develop structural reliability models	0206		
Develop M/E reliability models	0206		
Calibration of case studies	0209		
Publish report on structural reliability models	0209		
Publish report on reliability of M/E equipment	0209		
Publish report on calibration of case studies	0212		
Develop interim guidance and recommendations	0212		
Integrate components for inclusion to overall risk framework	0305		
Develop guidance on inspection/maintenance criteria	0309		
Publish final guidance and technical report	0309		

FUNDING	FY99	FY00	FY01	FY02	TOTAL
IN-HOUSE	35	210	310	280	835
CONTRACTUAL	65	50	30	00	145
TOTAL	100	260	340	280	980
FTE	0.25	1.0	2.0	2.0	

November 2000

Project: 33262-Prob of Failure of Gates, Equip & Warn Systems (CFF-L041)

General Project Information

Project Manager	**Organization**	**Direct/Reimbursable**
FOLTZ, STUART D, 217/373-3487	FACILITIES MAINTENANCE BRANCH	Direct Allotted

Program Manager	**Organization**	**Program Name**
JONES, HARVEY W. 601-634-3758	ITL-SCIENTIFIC & ENGRG APPS	521-Risk Analysis for Dam Safety

Customer/Proponent	**Point of Contact**
Headquarters--Civil Works	

Narratives

Problem

The risks associated with potential failures of dam gates and valves at spillways and outlet works is heavily dependent on the overall performance of mechanical, electrical, and structural components. Generally, the performance of a gate system is impaired by means of one or a combination of the following conditions: unusual or excessive hydraulic loading during extreme flood events; degradation due to corrosion, wear, and fatigue; structural imperfections due to construction error, inadequate design/application, and change of operating conditions; operational failure of the gate mechanism (e.g., misalignment, lack of proper lubrication, operator/PLC error and other detrimental conditions often induced by lack of proper maintenance); and functional failure of the driving electrical/mechanical equipment.

These components must perform successfully to maintain the reservoirs capability to control the discharges under normal, unusual, and especially extreme events such as PMF. Potential problems have been encountered on spillway systems during critical events. Failures at Folsom Dam and Red Rock Dam are two recent examples. In addition, with an overall decreasing Federal funding to maintain these components, minimal maintenance and infrequent inspection of these components will occur which will increase the probability of gate and equipment failures especially during extreme events.

Objective

The objectives of this work unit are to investigate and develop risk assessment methodologies and overall framework to determine and quantify the probability

of gate, equipment, and warning systems failures and associated consequences during normal, unusual, and extreme events. These objectives will be accomplished through work efforts in the following areas: (1) development of procedures for the identification of critical components and the evaluation of the probability of occurrence for critical events (event/fault trees) using Failure Mode Effects and Criticality Analysis; (2) development of a screening risk assessment tool for gate systems to determine if further detailed reliability analysis is required; (3) development of time-dependent reliability techniques to estimate the probability of failure of the associated driving electrical/mechanical equipment during extreme operating events; (4) development of time-dependent reliability techniques for the probability of failure of gate systems in dams (Failure in this case is defined as a critical state of the gate subsystem condition such that the set of gates ceases to perform its intended function); (5) informational survey of dam projects from the Corps of Engineers, Bureau of Reclamation, and other federal agencies to determine what type of warning systems and early-warning systems are currently in use, their operational successes/failures, and associated emergency plans.

Benefits

The products from this research will provide a rational framework for the comprehensive evaluation of the probability of failure of a given dam gate system under usual, unusual and extreme flood events. The technology will be used in other research areas under the Risk Analysis for Dam Safety Program as well as in other risk assessment R&D programs underway in the Corps of Engineers. Technology transfer to Corps districts, other Federal agencies, and private industry will be through written reports, technical guidance, potential software development, and technical workshops.

Work Description

The potential failures of dam gates and valves at spillways and outlet works during extreme events involve a complex sequence of event combinations and potential failure modes. This work effort will provide research in the following areas: 1) Identification of critical operating equipment and definition of potential failure modes for gates, valves, and operating components; 2) Establish event/fault trees for the structural and operating components to be used in Failure Mode Effects and Criticality Analysis (FMECA). Theses component combinations will require the incorporation of time-dependent aspects for both M/E and structural components; 3) Enhance current reliability techniques for M/E equipment in ETL 1110-2-549 to include load dependencies and system reliability concepts under extreme load events; 4) Perform reliability calibration of critical structural and operating components and investigate cross-correlation of reliability with Condition Indices; 5) Develop a screening risk assessment tool based on condi-

tion assessment to assist with investigating the need for further detailed reliability analysis; 6) Provide criteria for inspection and maintenance scenarios using both reliability analysis and condition index ratings; 7) Develop structural reliability models of spillway gate and outlet works components to assess the probability of failure of these components under various usual, unusual and extreme events; 8) Case studies will be selected to use in calibration of the risk assessment procedures and framework; 9) Conduct a survey and compare current warning and early warning systems and associated emergency plans in use at existing dam projects. If necessary, incorporate risk-based evaluation of flood and warning preparedness systems recently developed into FMCA model; 10) Develop interim guidance at steps during the program; 11) Develop final guidance with examples to assist District personnel performing a spillway and outlet works risk assessment.

Accomplishments
Implemented a Cooperative Research and Development Agreement with Hydro-Quebec. Conducted 3 meetings with Corps District attendees, US Bureau of Reclamation and HydroQuebec to develop inspection criteria and risk screening tool. Completed draft report evaluating FMECA methods.

Funding (K$)

Prior Years	CFY 2001	BFY 2002	BFY+1 2003	BFY+2 2004	BFY+3 2005	BFY+4 2006	BFY+5 2007	To Compl	Total
$200.0K	$70.0K	$280.0K							$550.0K

Appendix E: Civil Works Condition Index "Tree" (by Business Area)

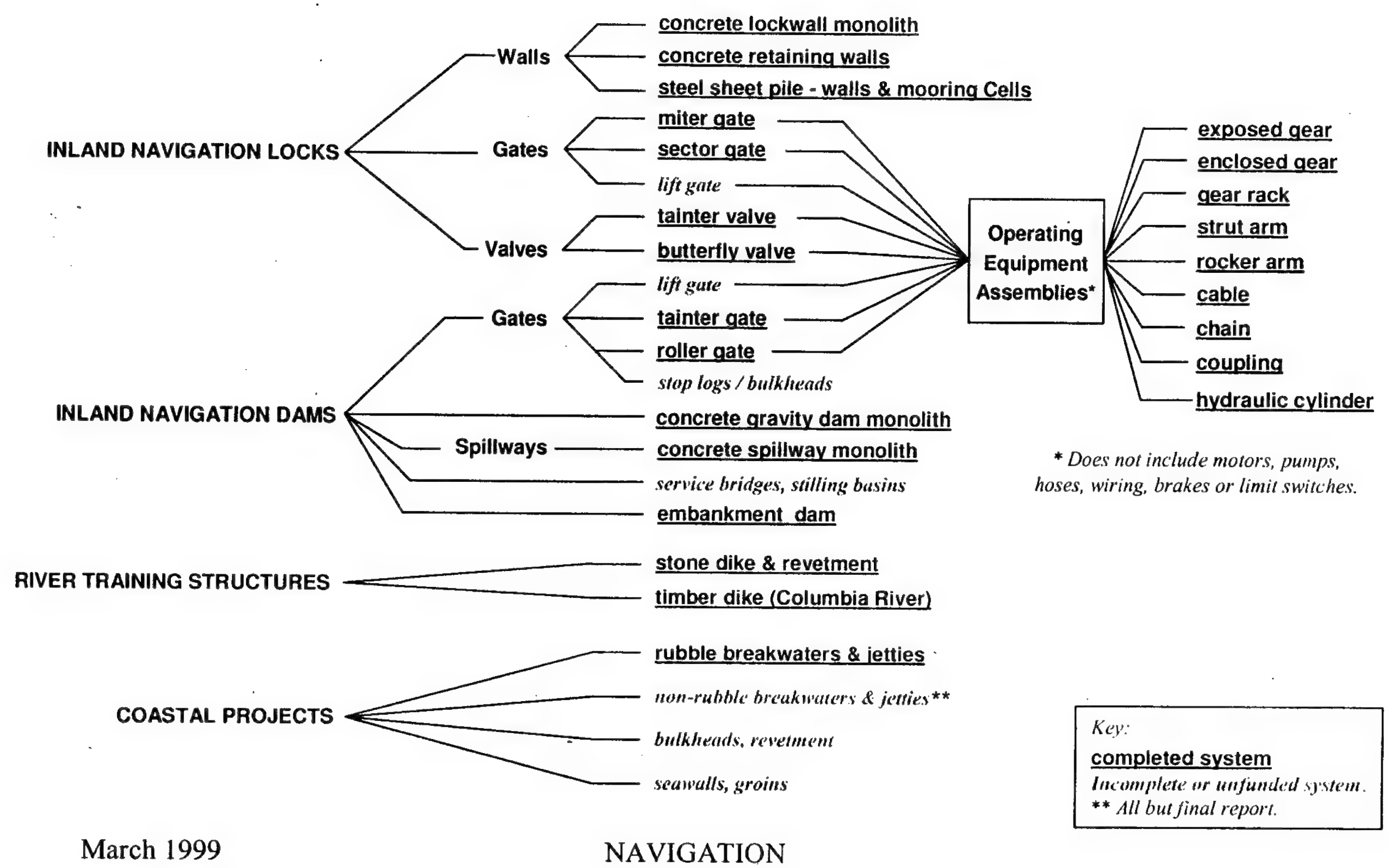


Figure E-1. Operations Management – Condition indexing for Civil Works navigation structures and subcomponents.

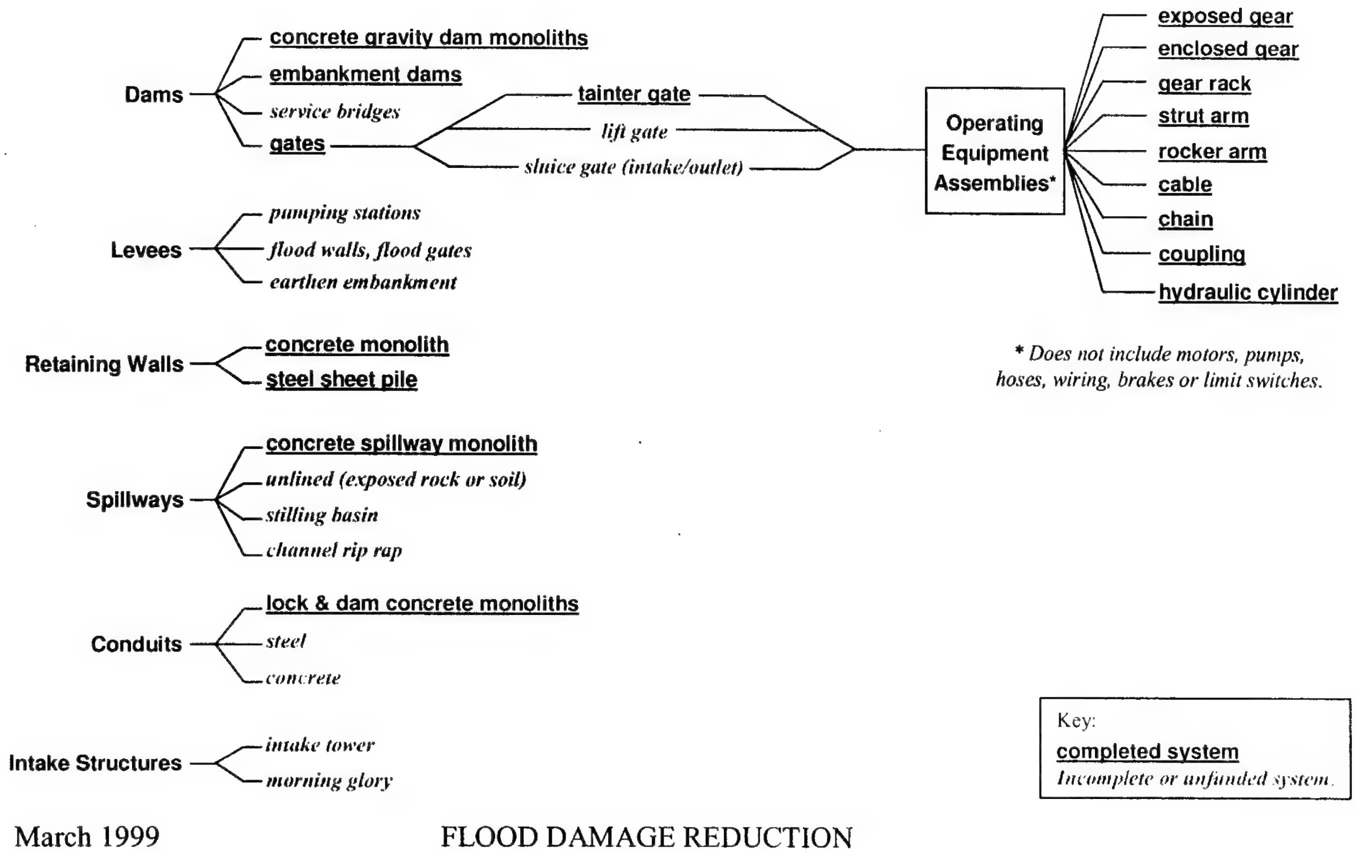
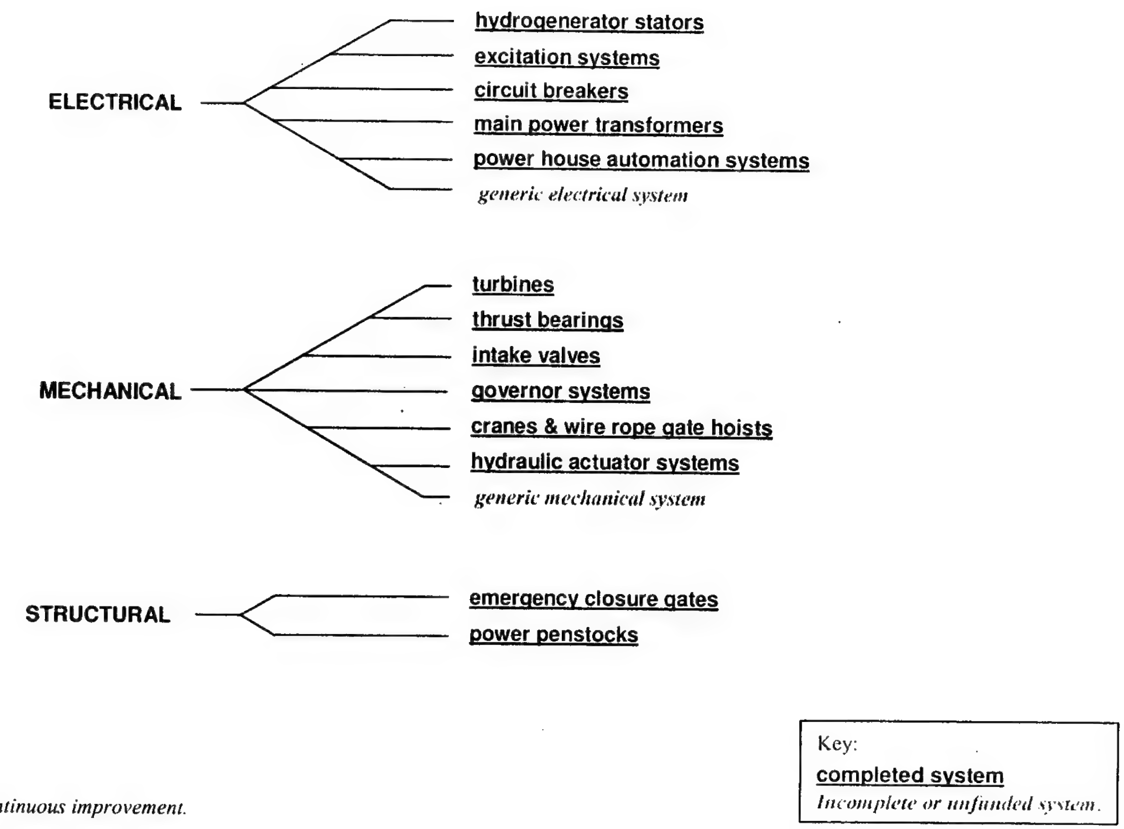


Figure E-2. Operations Management – Condition indexing for Civil Works flood damage reduction structures and subcomponents.



Note: Hydropower CI systems under continuous improvement.

Figure E-3. Operations Management – Condition indexing for Civil Works hydropower structures and subcomponents.

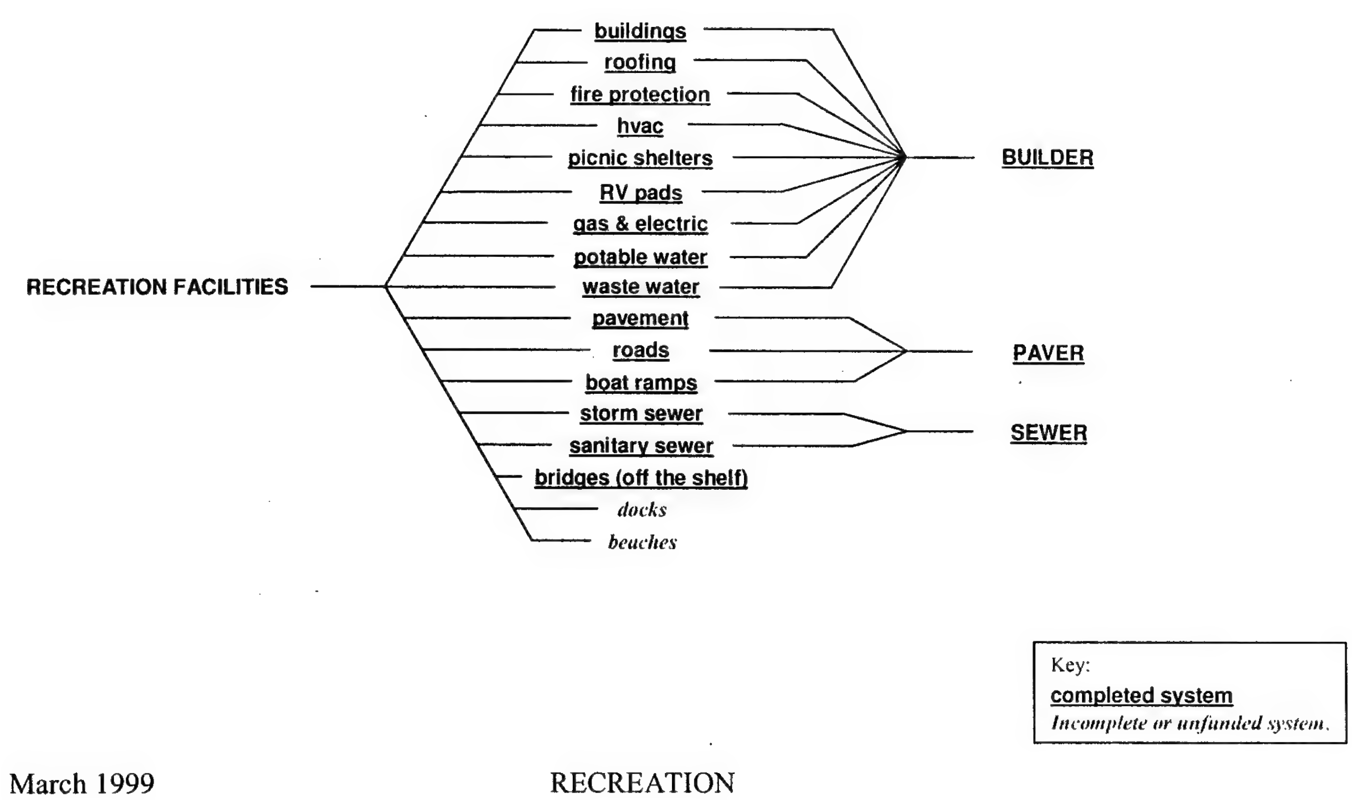


Figure E-4. Operations Management – Condition indexing for Civil Works recreation structures and subcomponents.

Appendix F: Condition Index — Problems, Benefits, Questions, and Opportunities

Perception exists that CIs are expensive.

Perception exists that CI is an unfunded mandate.

Perception exists that someone else will prioritize the budget based on CI ratings.

Perception exists that CI ratings will be used to distribute M&R money.
- take from one business area and give to another
- take from one District and give to another
- determining priorities without their input

Perception exists that CIs will be used to take evaluation/study/inspection money from one group and give it to another.

Perception exists that CI does not reflect the real priorities.

Perception exists that the information in the CI is already known. Inspector or engineer thinks he already knows everything that the CI might reveal.

Benefits of different CIs vary.
- Misperception of the benefits of one system based on knowledge of another CI.
- More difficult to implement CIs that have different benefits

Benefits of CIs are vague, communicated piecemeal, anecdotal, uncertain, etc.

Are CIs worth what they cost?
- How do we quantify their benefits?
- Why must the benefits of using CI be quantified but not the benefits of Periodic Inspections?

- What is the cost and what are the benefits of a periodic inspection?

Most Districts have used at least one CI. Most of these continue to use at least one CI.

Incomplete understanding of all the possible uses and benefits of CIs.
- find unknown problems
- opportunity to investigate the structure. Increased familiarity has benefits beyond just the CI.
- tells you what NOT to do. High CI increases District's confidence to: (1) cancel scheduled but unnecessary repairs, (2) delay dewatering, (3) delay periodic or other inspection
- reduce or replace other inspection needs
- format to discuss and prioritize problems
- communicate problems more objectively
- can assist comparisons between structures
- input for a benefits calculation
- support for the Corps budget request to OMB and Congress
- development of coastal work plans (contract scopes of work)
- historical reference with measurements of severity (as opposed to descriptions)
- tool to communicate information, experience, skills, etc. to next generation.

How can we make CI inspections cheaper?
- Should CI inspections be made simpler?
- What technology can we use to make CI inspections cheaper?

What CIs still need to be developed?

Electrical? Motors? Lift gates? Levees? Floodwalls? Pumping stations?

How do we overcome the inherent inertia against changing the business process?

CIs have a startup cost greater than their cost for continued use.
- Large percentage of structures should be inspected once, many may need less frequent re-inspection.
- Some gate measurements may require fabrication of mounting brackets.
- Coastal CI includes substantial effort to set up. Re-inspections are much easier.
- Embankment CI re-inspections take less effort.

Should the rating measure condition or need of repair? (Not all things in poor condition need to be repaired.)

Should the CI be an investigation (like gates), an evaluation (like embankment dam or coastal), or an objective rating tool (concrete lockwalls and dams)

- Should the CI try to quantitatively or objectively duplicate the Periodic Inspection?

Do we have any uniformity between index ratings for different CIs? Does a 60 for a gate equate to a 60 for concrete?

How does a user determine CI inspection frequency? Does it vary based on CI, condition, age, cycles, etc.?

Who should perform the inspections? Technicians or engineers? Operations or engineering? Does it vary by CI?

How does the CI information improve decisions on different types of expenditures? (This will vary by CI.)

- operational costs
- baseline maintenance and repair
- nondeferrable repair
- inspection
- dam safety
- construction general
- major rehabilitation

What information do CIs provide for dewatering?

- Can they be used to increase interval between lock dewaterings?
- How do they help plan for activities while dewatered?

How do we gain support from HQ engineering?

Is the CI an Operations encroachment on Engineering mission?

- How does it encroach?
- How do we make it part of Engineering business practice?

How do we market to the districts?

How can CIs be used to help differentiate deferrable and nondeferrable?

How do CIs support economic justification of M&R?

- What M&R benefits can CIs measure?

- How many benefits should we measure?
- How accurate do we need to be?
- Do CIs measure M&R benefits for recreation?

How does the CI interrelate with periodic and annual inspections?
- Can CIs be used to increase time between periodics?
- Should CIs be performed before or during Periodic Inspection?

How does the CI contribute to reliability and risk analysis?
1 – CIs in a quadrant-type tool. This could be a quicker, less expensive, and less accurate estimate of project reliability and MR&R benefits.
2 – CI information could be used as an input to more thorough reliability studies.
3 – CIs as an initiating activity to focus the risk analysis.

How does the CI contribute to Main Stem studies?

How can the CI be used to support dam safety objectives?

How does the CI relate to the level of service?

How does the CI contribute to GPRA?

How does the CI contribute to Performance Measurement?

How can CIs be used to monitor, measure, and improve performance?

Appendix G: Meeting Minutes

May 14, 1998 - Field Review Group Meeting

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Minutes of the 1998 FRG meeting on the FY1999 Civil Works R&D Program: Management Tools for O&M

The FY1999 Civil Works R&D Program review for Management Tools for O&M was held on 14 May 1998 at the Construction Engineering Research Laboratories. Attachment 1 is the program summary and agenda for the meeting. Attachment 2 is a list of personnel attending the meeting.

The focus of the field review group (FRG) meeting was:
Familiarize the group with the component condition indices (CIs) and the QUADRANT benefit cost model for O&M.
Determine district and project level utilization of the CIs and the QUADRANT model.
Discuss needs for linking the CIs to QUADRANT.
Present a status report on the CI-QUADRANT scoping study.
Make recommendations to assist in the development of the Management Tools for O&M program such that the research products will meet district and project needs and be consistent with district resources.

In summary the field review group (FRG) supported the expansion of the QUADRANT benefit-cost model to other CW business areas based on the outcome and recommendations of the scoping study (the other business areas include coastal navigation, flood control, recreation, and environmental stewardship). The FRG additionally supported some tie-in between the REMR developed CIs and QUADRANT. They supported the completion of CIs that are required for QUADRANT, and the development of simplified CI inspection procedures consistent with district resources. The FRG did not see the specific need for an objective functionally-based role-up of CIs to form a project or a project-business area composite index. But the FRG may be asked to revisit the composite index concept based on their acceptance and use of CIs and QUADRANT. The composite indices will not be developed in the initial phases of this work.

Paul Howdyshell

Attachment 1 - Program Summary Report

AREA TITLE

PROGRAM TITLE Management Tools for O&M

PROGRAM MANAGER Paul Howdyshell, 217-373-6762

TECHNICAL MONITOR Harold Tohlen, 202-761-0241

PROBLEM

Funding needs significantly outstrip the available programmed funds in the Civil Works Operations and Maintenance (O&M) program. Thus it is critical that the program managers of the Civil Works O&M program articulate both the cost and the benefit of the maintenance work to be accomplished and/or deferred in the program for the budget year. Objective and consistent benefit-cost analysis techniques do not currently exist for work package prioritization within and between Civil Works business areas.

OBJECTIVE

The objective is to develop a consistent benefit-cost model/procedure to support an objective prioritization/ranking of maintenance work packages in the annual Civil Works O&M budget. The benefit-cost models/procedures will be developed for all Civil Works business areas that have a significant maintenance budget requirement and an identified and quantifiable benefit associated with the maintenance activity.

DESCRIPTION OF WORK

This effort will build on the previously developed component level condition indexes (CIs) and the QUADRANT benefit-cost models for inland navigation and hydropower. Both the CIs and QUADRANT programs are input requirements for the Civil Works O&M Automated Budgeting System (ABS). The work to be accomplished will include: (1) expanding QUADRANT type benefit-cost models to all other Civil Works business areas that have a significant maintenance budget and an identified and quantifiable benefit associated with the maintenance; (2) developing objective and consistent procedures for translating the proposed maintenance work packages to changes in CIs, and changes in CIs to changes in the benefits used in the QUADRANT model; (3) developing input procedures for CIs and benefit-cost data that are consistent with project and district resources; (4) deploying and fielding the CI-QUADRANT benefit-cost package for O&M work package prioritization.

ACCOMPLISHENTS

This program is a FY99 new start. It integrates the CIs that have been developed under the REMR program with the QUADRANT benefit-cost models. CIs are objectively based, reproducible numerical indicators of physical and/or functional condition for structural components and equipment. CIs are completed for most inland and coastal navigation structures, hydropower equipment, and flood control structures. CI like systems applicable to recreation facilities have been developed under military funding for buildings, pavements, and utility systems. QUADRANT models are available for inland navigation (NAV-QUAD) and hydropower (HYDRO-QUAD). Studies are ongoing to scope QUADRANT type benefit-cost models for the remaining Civil Works business areas.

Funding
($000)

Prior Years	FY98	FY99	FY00	FY01	Total
0	0	600	975	690	2265

Attachment 2 - Agenda

CW Management Tools Program Review - CERL 14 May 1998

8:30 Administrative announcements and CERL welcome	P. Howdyshell & S. Kim **(15 min)**
8:45 Opening Remarks from CERD-C	T Liu **(10 min)**
8:55 Opening Program Comments from Proponent	Harold Tohlen **(20 min)**
9:15 Program Overview	P Howdyshell **(30 min)**
9:45 REMR CIs - Historical Perspective	D McKay **(20 min)**
10:05 Break	(15 min)
Program Component Briefings	
10:20 Summary Indexes – Maintenance work packages to changes in CIs – Changes in CIs to changes in benefit	D Plotkin **(15 min)**
10:35 Quadrant like cost benefit models for coastal navigation, flood control, and recreation and revisions to HYDRO-QUAD and NAV-QUAD	J Comiskey **(20 min)**
10:55 Methods to minimize input data requirements	P Howdyshell **(15 min)**
11:10 Deployment and fielding	S. Foltz **(20 min)**
11:30 Lunch	
12:45 Scoping Study	J Langowski **(45 min)**
13:30 Open Discussion – Field Issues	**(45 min)**
14:15 Closing Comments FRG and HQ proponents	**(Time as required)**
14:30 Tour of CERL	**(1 hr)**

Attachment 3 - List of Attendees

CW R&D Program Review
Management Tools for O&M

14 May 1998

Name	Symbol	Phone
Harold Tohlen	CECW-OM	202-761-0241
Bob Daniel	CECW-PD	202-761-8568
Gerald R. Melton	CESAD-ET-PE	404-331-6870
John Copeland	CEMVR-ED	309-794-5284
Jim Crews	CELRD-ET-CO	513-684-3057
Jim Fredericks	CENWP-PE-PE	503-808-4750
Edmond Rogers	CEMVS-CO-N7	618-452-7107
Duke Loney	CENWP-HDC	503-808-4235
Louis Logue	CEMVD-ET-CO	601-634-5882
Tony C. Liu	CERD-C	202-761-0222
Jim Comiskey	CEWRC-IWR-P	703-428-9068
Jack Langowski	PMCL	618-549-2832
Simon Kim	CECER-FL-P	217-373-7269
Dave McKay	CECER-FL-P	217-352-6511 ext 7375
Don Plotkin	CECER-FL-P	217-373-6749
Stuart Foltz	CECER-FL-P	217-352-6511 ext 7301
Paul Howdyshell	CECER-FL-P	217-373-6762

June 1998 Meeting

IWR Minutes

MEMORANDUM FOR RECORD

TO: Harold Tohlen, CECW-OP

FROM: Jim Comiskey, IWR

SUBJECT: After Action Report, QUADRANT - Major Rehab Economic Principles Meeting, 11 June 1998

1) A meeting was held at Vanderbilt Institute for Public Policy Studies (VIPPS) to discuss selected parameters surrounding the economic models that support QUADRANT. The goal of this meeting was to define solid direction from the participants on these economic issues so that the QUADRANT (and related) research could proceed in an effective and efficient manner.

2) Key representatives from the Corps and PMCL attended the meeting:

Bob Daniel	COE	202.761.8568
Jerry Foster	COE	202.761.8676
Cliff Russell	PMCL/VIPPS	615.322.8512
Stuart Foltz	CERL	217.352.6511 (x 7301)
Jim Comiskey	COE	703.428.9068
Jack Kiefer	PMCL	618.549.2832
Ron Conner	COE	202.761.0132
David Moser	COE	703.428.8066
Tim Feather	PMCL	618.549.2832

3) The meeting was a discussion session centered on the economic parameters that drive QUADRANT and major rehab tools in the Corps. David Moser provided an overview of major rehab procedures using the overheads found in Attachment A. Cliff Russell addressed the group based

upon a paper that was distributed to all participants before the meeting which is found in Attachment B.*

4) The highlights and decisions made through the presentations and discussion are provided below:

A. Major rehab analysis became formalized in the Corps in 1991. Risk-based benefit-cost analysis is required by OMB to help justify major rehab expenditures. The analysis focuses on reliability and efficiency benefits. It goes beyond simply asking the question: to fix or not to fix, but <u>when</u> it should be fixed. A strategy which includes the timing for major rehab is usually sought (e.g. stockpiling, spare parts, repair plan). Guidance for major rehab analysis is found in EP 1130-2-500 (30 Sep 96)

B. The base condition for which economic comparisons are made in major rehab is defined as the condition without the proposed rehab activity. The analysis assumes a "fix as fail" strategy which requires a prediction of when a project component would fail. Rules on what type of repair will be done for selected types of failures are identified.

C. Engineering based life-cycle cost analyses are used to predict future reliability and performance of structural components. Hazard functions are estimated that typically relate the probability of failure and component age. Adjustments are sometimes made based upon condition indices (CIs), but no clear empirical correlation between CI and performance has been identified.

D. Monte Carlo simulation is used to simulate the possible performance of components over a life-cycle. When components perform "unsatisfactorily," repair costs and other opportunity costs accrue. These repairs may adjust the hazard function or the component's age on the hazard function for the succeeding time in the life-cycle until the next "unsatisfactory performance" or the end of the life-cycle. Multiple iterations of the life-cycle provide an estimate of

* Attachments A and B are not included in this report.

the distribution of present value of life-cycle costs. Both the base condition, equivalent to the "without project condition" and all rehabilitation strategies are evaluated using the same approach. Benefits are calculated by comparing the present value of life-cycle costs of all strategies to the base condition. Decision rules within the model are based upon expected values.

E. A challenge in developing these models is to predict unsatisfactory performance in economic terms. Major differences between major rehab and QUADRANT procedures are that QUADRANT does not predict failure events and it requires specification of a time horizon. To form economic comparisons, QUADRANT (through dynamic programming) finds the least-cost way to get to the specified condition at the time horizon.

F. The target SI in QUADRANT is in no way related to policy or agency goals. It is simply a means of leveling the playing field so that comparisons can be made. Furthermore, the "notional" maintenance items that are used in QUADRANT ensure that "everyone plays by the same rules" and that the maintenance items will be comparable. (Even though they may not be in reality.)

G. For QUADRANT, it has been assumed that CI is an adequate means of judging reliability. Several participants stressed, however, that no empirical relationship between CI and reliability has been found. This is a very important issue. Formal reliability analyses cannot be afforded in the timeframe required for annual budget decisions. How many components could be evaluated? Some type of quicker means of making a reasonable assessment of condition is needed. The participants suggested that developing a look-up table to relate CI and reliability may be appropriate. Some means must be developed to provide the data for the table, however, since there is no empirically-derived basis for relating CI to reliability.

H. Major rehab uses PUP functions (probability of unsatisfactory performance). It would not be a big empirical challenge within the QUADRANT framework to replace CIs with PUP functions.

I. Degradation curves should be reviewed. The data on reliability should be compiled. New reliability studies and major rehab analyses should be reviewed (e.g., Upper Mississippi work). Use-

ful points of contact include: Jerry Foster (HQ), Wayne Jones (WES), Mary Ann Liggett (WES), Bobby Huey (STL).

J. The group concluded that a new version of QUADRANT should be developed which uses Monte Carlo techniques to simulate the life-cycle performance of components relying on engineering-based PUP values. Some of these could be initially based on expert judgment. Also, a fixed-time horizon would be used to evaluate the economic value of each maintenance item, exogenously establishing unsatisfactory performance and utilizes a long time horizon (i.e., 50 years). It will be useful to do a series of comparative runs to see if the results differ significantly between the original and new versions of QUADRANT.

5. Follow-up actions required based upon the results of this meeting are:

A. Tim Feather will examine the models created for major rehab and identify a strategy for developing a revised version of QUADRANT. He will coordinate findings with IWR.

B. Include the results of this discussion in the Scoping Paper that is being developed to support the Corps upcoming Civil Works Management Tools Research Program.

C. Continue to investigate the relationship between the work on CI, project performance, and reliability.

CERL Minutes

Memorandum for Record

Meeting date: June 11, 1998

Location: Vanderbilt Univ., Nashville, TN

Attendees: Stuart Foltz – CERL
Jim Comiskey – IWR
Dave Moser - IWR
Bob Daniels – CECW-P
Ron Connor – CECW-PD
Jerry Foster – CECW-E
Tim Feather – PMCL
Jack Kiefer (not Langowski) - PMCL
Cliff Russell – Vanderbilt

Subject: Discussion and re-evaluation of economic models for Quadrant. (Comment: I was surprised to see Jerry Foster at this meeting given the focus on economics.)

Introduction (Tim): There are some significant differences in the basic economic models used in Quadrant and Major Rehab. The basis of the day's discussion is to center on what's correct and incorrect in each method, what's common and what's different. Harold Tohlen has asked Bob Daniels and Ron Connor for guidance on economic models to be used in Quadrant.

First presentation: Dave Moser gave an overview of the economics in the major rehab process. Major Rehab analysis is designed to be comparable to a New Start analysis. The two possible benefits are (1) increased reliability and (2) efficiency improvements. Reliability has a minimum threshold of $5-8.5 mil and efficiency improvements have a minimum of about $1.5 mil. Under most circumstances, reliability is given preference over efficiency improvements. It is currently difficult to get any Major Rehab funding. There are not many new starts. There is also a large up front cost to prepare the analysis and study requirements in order to be eligible for funding. For smaller Major Rehab projects, districts are increasingly looking to fund these items out of their O&M budget. This has increased focus on Quadrant versus Major Rehab.

The analysis procedure for Major Rehab is outlined in EP-1110-500. Questions to be addressed include (1) Why now?, (2) What are the consequences

of doing nothing?, (3) Where is the most critical component?, (4) What are the overall economics of the rehab?

Dave stated that the hazard function (a form of reliability measure) used for hydropower components is based on age. He mentioned a "Norlin" factor for trying to modify the hazard function based on the CI. Dave stated that investigations had shown no correlation between CI and reliability. Question: What investigations and where is the documentation of the investigations?

Discussion comments:

Subjective probability assessment is used in Major Rehab and it needs benchmarking or spot checking to verify adequacy.

Increased inventory of spare parts would greatly reduce down time from failures. It might be more economical than some types of repairs for decreasing closure time.

There is a need to develop a procedure for optimizing the timing for Major Rehab. When should we investigate the possibility of Major Rehab?

Evaluation should be based on reliability not efficiency, but don't ignore opportunities for efficiency gains.

Major rehab is meant to reduce risk of failure and associated costs, but it doesn't eliminate the risk.

The major rehab analysis includes event trees, fault trees, Monte Carlo simulation, etc. The primary result is an expected value.

Major rehab evaluations commonly forget to subtract forgone project outputs during the rehab.

Second presentation: Cliff Russell attempted to explain how the Quadrant model worked and why it did what it did. He was soon and frequently interrupted. The Major Rehab model assumes that at the end of the evaluation period (approx 20-50 years) the "with" and "without" projects will either end with the same reliability or future cost discounting will cause the differences in project value to be insignificant. During the analysis period, there is only assumed to be normal maintenance and repairs to correct component breakdowns. The number of breakdowns and their associated cost (closure and repair costs) is lower with the Major Rehab. Quadrant is based on a ten year horizon and assumes the end reliability would not be the same under different scenarios so it factors in a cost (notional maintenance) for making the ending project condition at some equivalent high level for all alternatives.

The interruptions changed the focus of discussion from economics and reliability degradation models to the link or lack of a link between CIs and reliability. This discussion began very disjointed and multi-topical.

Dave Moser and Jerry Foster were convinced that there is no correlation between CIs and probability of failure. I stated some reasons why I didn't see how this could be true. Most CIs are largely based on subjective opinions of how serious particular measurements and observations are. I also suggested that a significant part of our work in the Civil Works Tools program would be to improve the link. This could take the form of better scaling and considering other factors such as age or loading cycles. I think this might have had some impact on Jerry.

Bob Daniels again brought up the question of whether we even needed SIs for anything. It was eventually determined that Quadrant should use "component" CIs – with "component" loosely defined as something ranging from CERL's component CI to the 5 "components" currently used in Quadrant. This does not imply that there are not other reasons for having SIs.

Jerry again brought up the inaccuracy of CIs. He gave an analogy of an old beat up Nova that he dropped a 457 into and it beat everything, but the CI would be low. I told him that the CI in that case was measuring the wrong thing. He didn't see how anything less than a full blown reliability study would give anything meaningful. Although the cost issue had already been brought up, I restated it. Reliability studies are very expensive. Most O&M maintenance is not large enough to justify nearly that level of analysis. Our objective in the Civil Works Tools program is to develop a much simpler and cheaper method of approximating the reliability study results. It almost seemed like Jerry had never thought of this. Then I seemed to satisfy everyone when I re-stated the need to improve the Quadrant model for estimating reliability and that the next model might not even include CIs.

It was suggested that we take the probability assessments from current reliability studies, perform CI inspections of those projects, and create an empirical model to match the reliability assessment as closely as possible.

(Summary) After lunch we basically continued the discussion.

- We determined to base Quadrant at some component level as stated above.
- An increase in loading cycles in a period increases the probability of failure in the period and Quadrant should consider this.
- We need to develop an empirical model to relate our "index" used in Quadrant to reliability. I took this as an unstated desire to reduce the dependence on subjective probabilities.
- We should compare our "index" to reliability probabilities calculated for current reliability assessments for creating an empirical model.
- Re-look at the decay function. (did that mean the CI/age curve?)
    - WES should have some risk analysis data on degradation
        - Jerry Foster, Wayne Jennings, Mary Ann Leggett
        - Bob Huey, St. Louis – in charge of upper Miss Nav study.

Conclusions: This meeting had more significance and importance than Tim Feather, Paul Howdyshell, and I expected previously. I also believe that many of the suggestions for action are likely to be the basis for a substantial portion of our work over the next three years under the Civil Works Tools program.

General questions:
Are the notional costs accurate?
Is the CI/reliability link correctly scaled?
Does the CI/reliability link need other factors?
How does the CI degrade with age?
What is the reliability degradation with age?

Specific questions:
- Should the evaluation be based on net benefits (current Quadrant method) or benefit ratio?
    - For a business with unbounded access to capital, ranking by net benefits may make sense, but I fail to see how that applies to the Corps. The Corps is under budget constraints that result in deferral of many repairs that analysis estimates show to have positive economic benefits. The Corps needs to optimize each dollar invested. Do we want to do a $100K repair with $1,000K in net benefits or a $1,000K repair with $2,000K in net benefits?
    - Secondly, this gives priority to large repair actions that may have a cost benefit ratio near 1. This means that relatively small errors in estimates could cause the ratio to be less than 1 and result in negative net benefits.
- References mention the difficulty of making global intuitive judgements, but discussion of Quadrant development tries to justify exactly such judgements. They also state that — as long as you are modeling the right things — bad models are better than subjective judgements.
    Are global judgements better than component judgements?
    Are subjective SI/CI judgements better than the inspection calculations?
- What is the impact of the estimated notional costs? If actual costs for a repair are greater or less than the notional, does that drive the results?
    - For example, what if the analyzed repair option had a cost of $1 million, is it possible that it could affect the notional costs by as little as $100,000 or as much as $10 million? If so, would this difference in notional and real costs be overwhelming to other costs and benefits?

March 4, 1999 Meeting

MEMORANDUM FOR RECORD

FROM: Jim Comiskey

(Comments by Stuart Foltz)

SUBJECT: Summary of 4 March 1999 Meeting on Research to Assess the Appropriateness of Condition Indexes and Other Components in the QUADRANT Maintenance Budgeting Tool

1. The meeting was held at the Institute for Water Resources (IWR) with representatives from U.S Army Construction Engineering Laboratory (CERL), Corps of Engineers Hydroelectric Design Center, and from USACE (CECW-P, CECW-OM, and CECW-E.) A list of attendees is attached.

2. The overall purpose of the meeting was to discuss the direction and range of issues related to research activities of IWR and CERL with respect to various components of the QUADRANT model and Condition Indexes.

3. Key Issues and Concerns Expressed by Meeting Participants:

   Mr. Jim Comiskey, project manager for QUADRANT at IWR, opened the meeting by stating that a principal goal of the meeting was to assist IWR in its study of the relationship of Condition Indexes resulting from research at CERL and Summary Indexes of QUADRANT to risk and reliability to identify how each index or system can support each other in future research activities.

   Mr. Michael Krouse, Chief of Research Division at IWR, expressed the desire to examine and assess the degree to which CIs relate to civil works project reliability and performance in making maintenance budget decisions.
   I don't think this statement is clear or complete. "...degree to which CIs relate to..." sounds like making a direct comparison. One question is what information CIs provide that can be used to improve detailed reliability estimates and identify causes of compromised performance due to infrastructure condition. In this role, CIs would be an additional parameter in reliability estimates. Closer to Krouse's statement, CIs and other information may be useful to make simplified reliability assessments for prioritizing ABS repair activities, repair studies, and possibly other packages. Even then, it's not a simple question of trying to directly relate CIs and reliability.

In his presentation, Mr. Paul Howdyshell of CERL summarized the following information about Condition Indexes:

–their purposes

–overall characteristics

–intended applications

–major advantages and disadvantages.

He also noted that there has been some confusion and misunderstanding about the real nature and original intent of these indexes. He hoped that this meeting may result in "clearing the air a little about CIs."

Another representative from CERL, Stuart Foltz explained, in his view, the three different types of condition indexes. In the first example, these indexes are simply "snapshots" of the physical condition of a structure at a given time (e.g., use of condition indexes for mitre gates in Nashville District). A second type of condition indexes involves their use in evaluation of cracks and/or volume of lost concrete in locks and dams while still another example of use of these indexes is aimed principally at helping Corps field personnel evaluate information. Mr. Foltz also stated that based on a CERL survey, while about 60 percent of Corps districts indicated that they had used CIs at certain times, none used them as they were originally intended: to provide a snapshot of condition of a facility at a given point.

All CIs are a snapshot of condition. The CIs for concrete are basically just a "snapshot." Those CIs primarily quantify the distresses and their severity. The Miter Gate and other gate CIs are a snapshot and more. They are investigative tools for finding distresses. The embankment CI is more for analysis of inspection information. It has no formal inspection procedure and is basically a framework for focusing on specific concerns and quantifying subjective analysis.

Paul made the statement about the CIs not being used as intended, but I don't think that's quite what he said or meant. Regardless of how they perform CIs inspections, they still can use the results as a snapshot of condition. Paul was referring to how districts perform CI inspections. Not to put words in Paul's mouth, but I think he said it's unlikely that any Districts use all the CIs (perform the inspections) as intended.

Mr. Jim Norlin from the Corps Hydroelectric Design Center stressed, in his remarks, the need to tie existing data and reliability studies to past outages and failure rates. He also emphasized the point that CIs only provide information about CONDITION of a facility and NOT its FUNCTIONALITY OR PERFORMANCE. CIs are NOT tools capable of predicting failure by themselves.
Jim Norlin's statements were hydropower specific. These quotes are not universally applicable to all CIs.

Mr. Mike Walsh of IWR stated that, no matter what type of civil works decision support tools we ultimately develop, they must allow people to define goals, identify decision criteria, set values for these criteria, and be capable of evaluation based on structured decision methodolgy.

The Corps hydroelectric power coordinator Mr. Craig Chapman noted that part of the failure to gain greater Corps support for QUADRANT and condition indexes may be due in part to reduced funding for national conferences on hydropower and related topics. He was also of the opinion that Corps field personnel may be more inclined or more comfortable in using condition indexes in preference to QUADRANT due to the "black box" type of its model for derivation of costs and benefits for repair and maintenance of Corps projects and facilities.

Mr. Ron Connor stressed the need for civil works management tools that need to take into account past and existing Corps major rehabilitation studies and, if possible, to integrate those applicable "screening" parts of these rehab studies into Corps model or algorithms to more cost-effectively manage civil works projects. Fundamental problems with QUADRANT include: (1) output are not compatible with Corps major rehabilitation studies and (2) there are theoretically any number of summary indexes that can be employed to arrive at a cost-benefit number that could justify its repair.
Huh?

Mr. Jerry Foster stated that more studies needed to be done before determining more precise use for condition indexes in Corps geotechnical studies (non-electrical or mechanical projects).
I don't remember his comment on this topic but I can't understand what is being said here.

POTENTIAL IWR STUDY ON RELATIONSHIP BETWEEN RISK/ RELIABILITY AND CONDITION INDEXES

A consensus emerged from the meeting that IWR will attempt to determine the following:

— Look beyond just the CIs and determine the relevance of QUADRANT model and its components to reliability, prospect performance, and functionality;

— How does the QUADRANT model reflect project performance and functionality of civil works projects;

— Can project benefits of maintenance expenditures be properly related in QUADRANT for purposes of analysis and

— Are there any other data or components relating to protocols used to compute CIs that can be used as predictors of reliability and performance?

As I see it, the current Quadrant model includes three steps: (1) a condition rating, (2) a relation between the condition rating and reliability, (3) a conversion of the reliability estimates into a dollar value. I haven't understood anyone to think these are the wrong steps. The discussion focuses on how to complete these steps.

Step 1 – do we use SIs, CIs, and/or other information?

Step 2 – Given we have the right input data, how do we properly scale and adjust the inputs (CI, age, cycles, etc.) to create an accurate reliability estimate?

Step 3 – Incremental analysis or Monte Carlo?

I'm not sure if this is what you're saying in the "consensus" statements or not.

I don't see any benefit in addressing the question of Incremental Analysis vs. Monte Carlo until we have some resolution of questions on the first two steps. These focus on CIs, SIs, other inputs, and their tie to reliability.

Attachment 1 - List of Attendees

4 MARCH 1999 MEETING ON CONDITION INDEXES AT IWR

NAME	CORPS UNIT	PHONE
Jim Comiskey	IWR	(703)428-9068
Jim Norlin	CENWP-HDC-A	(503)808-4225
Jack Lane	CEWRC-IWR-N	(703)428-8254
Arthur Hawn	CEWRC-IWR-N	(703)428-6242
Craig Chapman	CECW-OM	(202)761-1767
Ron Connor	CECW-PD	(202)761-0132
Paul Howdyshell	CECER-CF-F	(217)373-6762
Jerry Foster	CECW-ED	(202)761-8676
Stuart Foltz	CECER-CF-F	(217)352-6511
Michael Walsh	CEWRC-IWR-R	(703)428-7087
Michael Krouse	CEWRC-IWR-R	(703)428-6217
David Moser	CEWRC-IWR-R	(703)428-8066

May 26, 1999 Meeting

IWR Minutes

MEMORANDUM FOR RECORD

FROM: Jim Comiskey

RE: IWR/CERL 25 May 1999 Meeting on Use/Application of Condition Indexes in Civil Works Risk and Reliability Studies

1. The following individuals participated at this meeting:

Name	Organization	Telephone Number
Dave McKay	CECERL-FL-P	(217) 373-3495
Michael Walsh	CEWRC-IWR-R	(703) 428-7087
Jim Comiskey	CWWRC-IWR-A	(703) 428-9068
Jim Strecker	LDI Engineering	(515) 232-4638
Lowell Greiman	Iowa State University	(515) 232-4638
Jerry Foster	CECW-ET	(202) 761-8676
Bob Patev	CEWES-ID-E	(601) 634-4453
Jack Lane	CEWRC-IWR-N	(703) 428-8254
Stuart Foltz	CECERL-CFF	(217) 373-3487
Paul Howdyshell	CECERL-CFF	(217) 373-3491
Mike Krouse	CEWRC-IWR-R	(217) 428-6217

2. Jim Comiskey opened the meeting by asking each of the attendees to introduce themselves and emphasized the need to continue the dialogue on potential uses of condition indexes, developed by CERL, in Corps risk and reliability studies for O&M activities begun at a March 1999 meeting between CERL and IWR.

3. Mike Krouse, Chief of Research at IWR, thanked everyone for coming to the meeting and noted the Corps' desire to explore a variety of ways including condition indexes as well as the methodology developed under QUADRANT studies as means to better prioritize O&M expenditure items.

4. A more detailed agenda for the meeting was presented by Stuart Foltz, manager of the condition index project at CERL. This agenda included the following:

— What can reliability do or how can it be used?

— better definition of major and minor level of repair for O&M item

— application of risk/reliability studies in calculating varying degrees of project/project component studies

— status/implementation of QUADRANT project by IWR

— data needs vs. data collection in risk/reliability studies

— reliability-general overview

— maintenance item: components vs. major repairs

— incremental analysis vs. Monte Carlo simulation

5. Another participant at the meeting from CERL, Paul Howdyshell, was of the opinion that in the Corps there is no need to have a wide number of tools that can be utilized to prioritize O&M expenditure. It is also important to develop both a reasonable time frame and reasonable expectations about what future tools, if developed, can accomplish and communicate this message accurately to USACE. The Corps needs a way to do "quick and dirty" studies to assess expenditures on O&M items. Paul also suggested that condition indexes may be a more OBJECTIVE way of assessing needed O&M repairs than QUADRANT since the former are based on more precise engineering measurements and data. If funded by Congress, the development and field-testing of any new civil works O&M tool should be accomplished within a three year time frame and should first probably address the business areas of navigation and hydropower. Most of the condition indexes completed to date relate to these areas.

6. Jerry Foster, a member of the geotechnical staff at USACE, stated that reliability/risk studies may be a good way to screen projects for unneccessary repairs that may be made simply due to the end of a certain time frame or business cycle and thereby save the Corps substantial O&M funding. He also stressed the need to relate condition indexes, in some meaningful way, with performance. The Corps maintains a range for expenditure of O&M funding, i.e., deferrable, non-deferrable etc. In rehabilitation studies, Corps examine components of projects, not their "nuts and bolts." In these same studies, the goal is to ascertain whether a project will perform satisfactorily rather than whether it will fail. With respect to reliability, the Corps examines a "span of reliability" and focuses on items that affect performance. The actual level of satisfactory performance of a project is determined at district level. Too, in

rehabilitation and other O&M studies, Corps only collects data that is necessary to complete study. Consequently, there is not a lot of data available for use in non-project specific purposes, including the development of tools to generically assess O&M expenditure. If a number of studies were available and a model calibrated properly, it may be possible to predict performance of project at some level of confidence without performing usual and generally expensive rehabilitation studies.

7. An engineering firm that has assisted CERL in completion of condition indexes, LDI, was represented by Jim Stecker. He noted that, in general, condition indexes are not developed to examine a project's performance. He also stated that more than 50 percent of items covered in inspection visits may only require a day's work or so for repairs. As a result, performing extensive studies on such items would be a very redundant use of Corps funds. Jim Stecker also provided the following suggestions/information:

   — For any generic type of rehabilitation studies, there must be a good set of data for baseline purposes

   — At the present time, there are no condition indexes that cover electrical motors of the commercial type

   — Condition indexes for steel and concrete may be inadequate for use in extrapolating data about these building materials in other rehabilitation/O&M studies.

8. A CERL contractor from Iowa State University, Lowell Grieman, stated that condition indexes used in Corps repair and rehabilitation studies must be solidly based on good risk and/reliability data before being applied to economic models. He also asked whether safety considerations were part of rehabilitation studies.

9. Bob Patev of WES suggested that both rehabilitation studies and condition indexes done for projects on the Ohio Main Stem may be a good place to start collecting data to ascertain whether these studies and indexes are, in any way, correlated. He noted that some of the studies done for the Upper Mississippi River could be used if they were updated, since studies relating to this part of the country were performed before more recent rehabilitation guidance was implemented.

10. Mike Walsh of IWR noted that, out of approximately 20,000 work packages submitted to USACE for O&M work, about only 400 involve amounts of

money in "borderline or cutoff range" and would consequently be used in any new QUADRANT-like tools developed using condition indexes.

MEETING CONCLUSIONS/RECOMMENDATIONS:

1. Between now and end of fiscal year, IWR and CERL will begin to collect applicable rehabilitation/O&M studies and conditions indexes to determine any data correlations.
2. CERL will prepare a three-year plan for developing tools to prioritize O&M funding items if money is secured by Congress for this purpose.
3. A copy of IWR's task order for review of QUADRANT was provided to CERL for comment/and or review.

CERL Minutes

MEMORANDUM FOR RECORD: Summary of 25 May 1999 meeting on research to improve understanding of Reliability and how it might relate to Condition Indexes

FROM: Stuart Foltz

The objective of this meeting was to discuss topics that did not receive adequate attention in the March 4 meeting. The topics previously overlooked were an overview of reliability and discussion of possible connection between it and CIs. The meeting was held at this time primarily because the out-of-town participants were in town for another meeting. Unfortunately, Dave Moser was not available but Bob Patev served as the "expert" on reliability.

A copy of IWR's task order for review of QUADRANT was provided to CERL for comment/and or review. Stuart mentioned that the Scope of Work appeared to have little connection with the original objective given to IWR of investigating relationships of CIs to reliability and performance. Mike Krouse and Jerry Foster stated that the original objective had been modified at the March 4 meeting.

Stuart Foltz wrote down some topics on the board that could be explained or discussed:

- — Reliability-general overview
- — Data needs vs. data collection and availability in risk/reliability studies
- — Level of maintenance activity vs. CIs and Quadrant components and SIs
- — Use of incremental analysis vs. Monte Carlo simulation
- — Status of IWR's FY99 work on CIs/reliability
- — Status/implementation of QUADRANT project by IWR
- — Determination of "Maintenance items," "Minor repairs" and "Major repairs"
- — What can reliability do or how can it be used?
- — Application of risk/reliability studies in calculating varying degrees of project/project component studies

Numerous concerns became evident in the discussions of reliability:

- — Reliability is a logical framework for calculating probabilistic outcomes based on statistical and analytical data.
- — Lowell Greimann asked numerous questions about reliability in order to develop a better understanding. The general result was an awareness of many difficulties in determining the true reliability.

— In many cases, the statistical data is limited. In some cases, the data is created based on subjective estimates of probabilities. In time, the database will increase and improve in quality, but there will probably always be some unique cases.
— The data often poorly represent the specific scenario. There are at least two different levels of misfit.
  - Generic data is used. For example, using data for motors in industrial settings that operate indoors instead of outside or in continuous use instead of intermittent. This may be avoidable as the Corps creates its own performance data.
  - The data does not consider all the relevant parameters affecting performance. Statistical data is generally based on "normal" conditions or other projections. As the database of historical information grows, more parameters can be considered but probably never all. Additionally, there is limited ability to confirm the assumptions for specific structures or components.
— CIs may help adjust reliability assessment to account for unaccounted or hidden parameters and for other deviations from expected behavior.
  - One difficulty is in fitting the specific need. The CI may not be a measure of the specific parameters that need to be considered.
  - Subjective estimates can be made to determine how to adjust performance database on CIs. In order to use CIs to accurately adjust reliability estimates, a large database is needed.

Mike Walsh mentioned new research on prioritization of budget packages based on quantitative parameters titled Multi-Attribute Prioritization. The importance of the parameters is to be subjectively determined and probably will not be tied to a dollar value. Questions raised included (1) what is the basis for relative importance of the parameters, particularly between different business areas? and (2) How does this help defend the budget if it isn't tied to an economic justification?

Stuart Foltz mentioned the possibility of looking at projects with recent or current reliability assessments and collecting CI data to compare to the reliability data. This had general support, particularly from Mike Krouse and Jim Comiskey. Bob Patev suggested that Ohio Main Stem rehabilitation may offer the best opportunities. The upper Mississippi studies also offer good possibilities. Jim suggested that he contact Stuart to work on determining possible projects for comparisons.

Attachment 1 - List of Attendees

Attendees at May 25, 1999 Meeting On Condition Indexes at IWR

NAME	CORPS UNIT	PHONE
Jim Comiskey	IWR	(703)428-9068
Jack Lane	CEWRC-IWR-N	(703)428-8254
Paul Howdyshell	CECER-CF-F	(217)373-6762
Jerry Foster	CECW-ED	(202)761-8676
Stuart Foltz	CECER-CF-F	(217)352-6511
Michael Walsh	CEWRC-IWR-R	(703)428-7087
Michael Krouse	CEWRC-IWR-R	(703)428-6217
Dave McKay	CECER-CFF	(217)373-3495
Bob Patev	CEWES-ID-E	(601)634-4453
Lowell Griemann	Iowa State	(515)294-5586
Jim Stecker	Iowa State	(515)232-5542

FRG Meeting 17-18 Nov 1999

MEMORANDUM FOR RECORD

Subject: Field Review Group Meeting on Management Tools for O&M Program

1. On 17-18 Nov 1999 a field review group meeting was held at the Rosemont Suites Hotel, Chicago IL. Field personnel in attendance included: Ed Rogers, CEMVS-CO-N7; Duke Loney, CENWP-HDC; Scott Vowinkel, CELRD-ET-CO(GL); Louis Logue, CEMVD-ET-CO; Ernie Drott, CELRD-ET-CO; and Dan Beasley, CESAJ-CO-O. Headquarters personnel included: Harold Tohlen, CECW-OM; Lillian Almodovar, CECW-PD; and Tony Liu, CERD-C. Research personnel who participated included Mike Krouse, CEWRC-IWR; Mark Slaughter, CEERD-CF-F; Dave McKay, CEERD-CF-F; Stuart Foltz, CEERD-CF-F, and Paul Howdyshell, CEERD-CF-F.

2. The meeting was initiated with opening remarks and comments by the HQ USACE staff, Harold Tohlen, Lillian Almodovar, and Tony Liu. Harold Tohlen reviewed the transition and changes in program direction since the initial FRG meeting in May 1998. In summary his overview indicated that Congress had zeroed the appropriation for the effort in FY99 and supported it at a $500K funding level in FY00. Changes within the program included one new initiative, O&M Cost Reduction Handbook, and a requested FRG reassessment of the Summary Indexes work unit. The Summary Index work was not supported at the May 1998 FRG meeting but Tohlen indicated the new command emphasis on identifying the appropriate or optimum O&M funding levels requires better metrics and models. Thus Summary Indexes to assist in assessing condition changes over time versus O&M funding levels is a needed tool. Tohlen indicated that the O&M Cost Reduction Handbook was an opportunity and directly supported the lessons learned initiative in O&M Top 10 Plus 1. The O&M Cost Reduction Handbook is an Internet accessible handbook of successful O&M research work that has been field proven but not fully utilized throughout the Corps of Engineers.

3. Lillian Almodovar indicated that the Planning and Program Division continues to be interested in modeling techniques to assist in work prioritization. Tony Liu provided the HQ R&D overview on the objective of FRG meetings and appropriate outcome.

4. After the introductory remarks, R&D work unit briefings were given by the research personnel followed by related presentations from MVD, LRD, and IWR. Paul Howdyshell kicked of the research briefings with an overview of the entire

program and the proposed changes since the May 1998 FRG meeting. This presentation complemented the introductory remarks by Tohlen and no significant discussions resulted from the presentation.

5. Dave McKay presented the Simplified CI Inspection Procedures work unit. The focus of the work unit is 1) Simplification of CI inspection procedures, 2) Completion of existing CI documents, 3) Enhancements (or needed revisions), 4) New starts. FRG comments that related to the work unit included the importance of simplification (inspection efforts need to be 20 to 50% of current procedures but maintain 80% of the current CI integrity). CIs should be included in O&M work packages, but they currently do not do this well. Both additional-new CIs and simplified CI inspection procedures need to be based on inspection efforts similar to the Army ISR (Installation Status Report) system of red, amber, green, but still maintaining as much of the traditional CI rigor as is technically possible.

6. Stuart Foltz presented the Summary Index work unit. The focus of the work unit is to develop an index for physical and functional condition of a project or site. The work will include the composite CI required for the O&M work packages in ABS and build to a project level SI. The project level SIs can be used to track overall project health and the relation between funded maintenance activities and condition over time. The FRG comments presented in the Simplified CI Inspection Procedure work unit are also applicable to this work unit. Contrary to the May 98 FRG meeting, there was some field support for the site/project summary index.

7. Paul Howdyshell presented the O&M Cost Reduction Handbook work unit. The Internet accessible electronic handbook will provide CW districts with easy access to field validated best practices that have been developed by the laboratories in support of O&M. The FRG concurred in the need and usefulness of the handbook, and that making the handbook Internet accessible was appropriate. Some reservation was voiced about the difficulty in using word or key word search techniques for data retrieval. Also Harold Tohlen indicated that he supported only the proposed level 1 product (title and paragraph abstracts), but it was indicated that the level 2, Tech Data Sheets and level 3 reports and specifications would only be included if electronic copies already existed and no additional work was needed.

8. Stuart Foltz presented the Benefits Analysis work unit. The work unit focuses on quantifying maintenance and repair benefits for work package prioritization and budget defense. The initial effort is to look at the various prioritization schemes that have been or are being proposed and recommend a path for

O&M to take. The FRG was very supportive of this initiative and Foltz's understanding of various ongoing activities including those that are currently being led by the divisions. It was proposed that the CERL research staff should participate in the division led initiative to get some form of multi-attribute scheme ready for the next budget cycle starting in March 2000. This jump starts the R&D initiative and assures that the remaining R&D is consistent with the needs of the field and their current direction. Some discussion was held on the merits of the QUADRANT scheme of dollar-based benefits analysis in O&M work package prioritization. It was concluded that the current form of QUADRANT had several problems but the QUADRANT or dollar-based benefits analysis scheme should not be completely abandoned at this time.

9. Following the Benefits Analysis work unit presentation, Louis Logue, Ernie Drott, and Mike Krouse made presentations on respectively the MVD, LRD, IWR work related to O&M work package prioritization. As a result of these presentations there was a decision that LDR would host a meeting of MVD, SWD, SAD, LRD, and CERL to discuss the division-led effort for developing a prioritization scheme for the next budget cycle (FY02) starting in March 2000. The meeting was tentatively scheduled for Nashville on the Week of Dec 6-10 (the attached MFR* from MVD provides additional background).

10. The meeting concluded with the assessment of FRG support and prioritization of the four work units. All work units had field support. The ranking of the work units from top to bottom is:

Benefits Analysis (work package prioritization)
O&M Cost Reduction Handbook
Simplified CI Inspection Procedures
Summary Indexes

11. The final action was to propose that the next FRG meeting should be held in August 2000.

Paul Howdyshell

* The MFR is not included in this report.

FRG Meeting 7-8 Aug 2000

MEMORANDUM FOR RECORD

Subject: Field Review Group Meeting on Management Tools for O&M Program

1. On 7-8 August 2000 a field review group meeting was held at the Southwest Division Office, Dallas, TX. Field personnel in attendance included: Ed Rogers, CEMVS-CO-N7; Duke Loney, CENWP-HDC; Ernie Drott, CELRD-ET-CO; Jim Fredericks, CENWD-NP-ET-WP; Gerald Melton, CESAD-ET-P; Stanley Ebersohl, CEMVS-CO-N; and Dan Beasley, CESAJ-CO-O. Headquarters personnel included: Harold Tohlen, CECW-OM; Jim Hilton, CECW-O; Lillian Almodovar, CECW-PD; and Tony Liu, CERD-C. Research personnel who participated included Mike Walsh, CEWRC-IWR; Dave McKay, CEERD-CF-F; Stuart Foltz, CEERD-CF-F, and Paul Howdyshell, CEERD-CF-F.

2. Tony Liu gave an overview of a new program that CERD is promoting. It is focused on providing direct support to the field. The support would range from answering calls and questions by phone or e-mail to going on-site for a few days to work with the district on-site. Tony also mentioned Dr. Link's proposal to get the R&D budget increased from less than 1% of the CW budget to 2%. Part of the increase would be by including some budget items such as studies in the research budget.

3. After the introductory remarks, R&D work unit briefings were given by the research personnel followed by related presentations from MVD, LRD, and IWR.

4. Dave McKay presented the Simplified CI Inspection Procedures work unit. The focus of the work unit is 1) Simplification of CI inspection procedures, 2) Completion of existing CI documents, 3) Enhancements (or needed revisions), 4) New starts. Dave discussed efforts to measure the time for CI inspection tasks and the difficulty in measuring the impact on integrity. Numerous tasks can be reduced or removed from the inspection with minimal impact. Dave also discussed a second approach to minimizing the inspection effort. This could be accomplished by having multiple levels of inspection. This would have similarities with annual, periodic and special inspections. The proposed levels include: records or knowledge based, visual inspection checklist, detailed CI baseline inspection and needs-based targeted CI inspections, and finally, special inspections when investigation beyond the CI level is desired. Dave also talked about enhancements to existing CIs and potential new starts to develop CIs.

5. Duke Loney completed the Simplified CI Inspection Procedures presentation by reviewing the work on hydropower. He discussed work on the hydropower CI notebook to remove some chapters and clarify the remaining information. He discussed MICAA as a replacement for the generator CI, identification of the most important data and inspections within each hydropower CI, and developing guidance to better utilize information collected by operators and suggest additional information that they could easily collect as part of their routine maintenance.

6. Stuart Foltz presented the Benefits Analysis work unit. The work unit focuses on quantifying maintenance and repair benefits for work item prioritization and budget defense. The initial effort was to look at the various prioritization schemes that have been or are being proposed and recommend a path for O&M to take. These efforts continue with the prioritization workshop immediately following the FRG meeting and a meeting with SWD in September. Beyond assisting the Division efforts, the role of the work unit remains somewhat uncertain. Further efforts will be dependent on the success of the Division efforts and discussions at the MSC operations chiefs meeting in October.

7. Stuart Foltz presented the Summary Index work unit. The focus of the work unit is to develop an index for physical and functional condition of a project or site. The work will include the composite CI required for the O&M work items in ABS and build to a project level SI. The project level SIs can be used to track overall project health and the relation between funded maintenance activities and condition over time. Much discussion focused on the definition of terms; component, structure, project, composite, etc. Support for continuing the work was mixed but less than 50% and the work unit is to be dropped.

8. Dave McKay presented the O&M Cost Reduction Handbook work unit. The Internet accessible electronic handbook will provide CW districts with easy access to field validated best practices that have been developed by the laboratories in support of O&M. The FRG strongly urged that all entries in the database include a field contact involved in application of the technology.

9. The meeting concluded with the assessment of FRG support and prioritization of the four work units. They voted to continue work on three work units. Summary Indexes did not receive 50% support. The ranking of the work units from top to bottom is:

Benefits Analysis (work item prioritization)
O&M Cost Reduction Handbook (tie)
Simplified CI Inspection Procedures (tie)

Summary Indexes

10. A target date for the next FRG meeting was not set. It will probably be in August again.

Stuart Foltz

Appendix H: Initiatives in Decision Support Tools for Operations Management

OPSMGMT December 2, 1991

INITIATIVES IN DECISION SUPPORT TOOLS FOR OPERATIONS MANAGEMENT

by

James E. Crews and
John P. Elmore[1]

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) is responsible for the operation and maintenance (O&M) of many of the projects it has constructed. Notwithstanding the vast inventory and increasing age of these projects, intensive management is an imperative since the O&M program is now the largest USACE program and spending has increased in real terms over the last 15 years and continues to grow.

The O&M program is the most functionally diverse and geographically dispersed program within the USACE. Thousands of activates are financed in this one account. The complexity of the O&M program makes finite analysis of the program difficult, nonetheless explanation and justification of funding requests is becoming increasingly more important in times of budgetary constraints.

The Corps O&M budget is formulated to emphasize those priorities and budget targets provided through the Assistant Secretary of the Army (ASA(CW)) and the Office of Management and Budget (OMB) budget development process. When the Administration's budget proposals are reviewed by the appropriation committees in the Congress, the priorities of many constituencies are expressed by reductions and additions to the budget. Frequently, Congressional adds are expressed in report or act language with no increase in corresponding funds. Thus, USACE has to rebalance its proposed program to reflect these changes.

Throughout the execution year, the O&M program requires intensive and constant review to insure the management of resources in an efficient and effective manner. While the mere size of the O&M program dictates management attention, further identification of efficiencies and sources of cost savings within this program is a continuing imperative but not without difficulty.

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[1]Deputy Chief and Chief, Operations, Construction and Readiness Division, respectively, Headquarters, U.S. Army Corps of Engineers, Washington, DC.

For all of these reasons, the USACE has engaged in considerable efforts to seek opportunities to better manage information, its fiscal resources and the allocation of those resources. The purpose of this paper is to provide information on USACE initiatives in developing decision support tools for decision makers in the operations arena. The paper discusses the current research efforts and analyses underway and their collective effort as a package to foster better decision making at all levels of the USACE.

PRESENT USACE BUDGETARY DECISION PROCESS

The process in which operation, maintenance and rehabilitation (OM&R) allocation decisions are made at USACE, Major Subordinate Commands (MSC) and their districts utilizes a series of decision nodes. Each node represents one of four operational levels in the USACE organizational hierarchy where USACE personnel make choices regarding future OM&R work efforts.

At each node, work packages are formulated, justified and grouped or rank-ordered by individuals with expertise that bear on the process. These individuals may be budget technicians, site managers, branch chiefs of OM&R-related mission components, program analysts or heads of principal functions. This collective body works together to meet time requirements for budget development and execution to fund priorities for the budget year.

If all things were equal; i.e., the MSCs all rank-ordered and prioritized work packages uniformly with comparable data, then there would be less need for the development of decision support tools or higher authority review of the budget. Only limited review for funding allocation would be necessary; however, there are differences within the MSCs that alter the flow and impact of decisions. These differences can be characterize as: technical; personnel; and organizational.

If we are to develop management tools that allow us to prioritize work elements at the margin so that all decision makers would arrive at the same conclusion, then we must address the differences noted above. The following sections discuss these efforts.

ONGOING DECISION SUPPORT TOOL EFFORTS

Several studies and research efforts are underway that should enable us to make better informed decisions concerning the allocation of OM&R resources. Each research effort or study is identified below and subsequently discussed. At the end of this paper these program elements are brought together so that the

reader will have an understanding of the focus for future corporate decision making. These studies and research efforts include:

a) Repair, Evaluation, Maintenance and Rehabilitation (REMR).

b) Improvement of Operations Management Techniques (IOMT).

c) Risk Management

d) Major Rehabilitation Reliability Index

e) Hydropower Investment Strategy

f) Policies and Procedures Option Study for Project Operation and Maintenance.

A. REMR

Over the past five years, the REMR research program has been focused on an Operations Management System designed to provide:

a) Objective condition assessment procedures.

b) A means for comparing the condition of facilities and tracking the change in condition over time.

c) Procedures for cost analysis of different maintenance policies and rehabilitation alternatives.

d) Computer software for storing and organizing data, performing calculations and producing a variety of reports.

This effort has produced the means for calculating condition indices (CI) for a variety of structures to date. These include:

a) Sheet Pile Structures - Guide Wall; Lock Wall; Mooring Cell

b) Lock Gate - Miter Gate; Sector Gate

c) Concrete Lockwall

d) Filling and Emptying Values - Tainter; Sector; Vertical Lift

e) Training Dike - Timber; Concrete Pile; Rubble Mound; Hybrids

f) Breakwaters/Jetties - Rubble Mound

g) Hydropower - Generators; Excitators; Circuit Breakers; Turbines; Transformers

Condition Index methodology for other structures and their components are in progress. Efforts are being made to have all CIs completed by FY 96. The computer software to perform the calculations and produce reports is being written to handle all CIs regardless of the type of structure being analyzed. A more complete summary of the REMR Management Systems can be found in the accompanying Executive Summary.

B. IOMT

The IOMT program is using existing information and experience of the MSCs to provide measurable means for reducing cost and increasing the safety and efficiency of OM&R management to enhance the utility of O&M assets and to address economic and budgetary issues in the O&M function. Some of the related work efforts underway include:

a) Incremental Analysis Techniques for Resource Allocation Decision Making.

b) Application of Decision Based Software to Water Resource Project Management.

The IOMT research program is a continuing effort covering a broad range of operations management issues. The ones mentioned above have outputs related to the overall issue of decision support tools. These two effort will be completed by FY 94.

C. Risk Management

Decisions on every element and project in the USACE program entails consideration of the risk that something may happen that would lead to partial or total unsatisfactory performance of the element or project. USACE projects are designed to accommodate certain possible events while continuing to function properly. However, if every potential risk were to be accommodated, the resulting project would be prohibitively expensive. Therefore, risks must be balanced in terms of costs and impacts to achieve a reasoned decision. In the O&M program, the decision of when to rehabilitate a structure, rather than continue incremental repair requires an explicit risk-benefit analysis. Maintenance dredging also requires a similar analysis since variable hydrologic events must be accommodated.

D. Reliability Index

Major rehabilitation decisions are usually commitments to invest large sums of money over several years to restore a

project to a condition that will extend its useful life, reduce downtime for scheduled and unscheduled repairs and enable the project to provide an economical level of services to its users. Rehabilitation is an opportunity to make projects last longer, be more dependable and to improve service.

The major rehabilitation program in the USACE has declined from the late 70s and early 80s to almost nonexistent in the late 80s and into the 90s. Increasing use and deterioration of our projects has led to revitalization of this program. With limited resources, however, establishing rehabilitation priorities becomes paramount. One tool being explored to aid in this endeavor is the reliability index.

Reliability focuses on the probability of a structural component's unsatisfactory performance and whether this is likely to increase with time. Reliability indices, like CIs, are measures designed to be sufficiently consistent for prioritizing structural rehabilitation investments.

On November 1, an EC and accompanying working papers were disseminated to the MSCs describing the process and information needed by HQUSACE for evaluating major rehabilitation projects.

E. Hydropower Investment Strategy

The hydropower investment strategy study is a follow-on to an earlier joint effort between engineering and operations to estimate the future investments needed to maintain our hydropower facilities. The earlier study, however, did not address how or where these funds would be obtained.

The goal of this study is to identify the best strategy for funding future hydropower investments required to operate, maintain, rehabilitate and upgrade existing hydropower facilities. This strategy will be developed by evaluating alternative strategies that define a set of actions that affect the operation, non-routine maintenance, and upgrades as measured against policy, legislation, procedures and financing.

The study is scheduled for completion by the end of calendar year 1991.

F. Options Study

The objective of the Policy and Procedures Option Study is to assure that Federal expenditures for OM&R provide justified levels of service in the least costly manner. The immediate output of this study is expected to be practicable measures -- policies and procedures -- that can be applied towards that end. It will not yield specific project proposals, but rather actions for achieving results.

Four broad themes are being investigated in this study. These are:

a) Program Development, Execution and Monitoring - Can management of the OM&R activities improve through changes in budget development, execution and monitoring procedures? The study is looking at alternative ways to achieve a closer linkage between the OM&R budget presentation to the Congress and how appropriated funds are actually used; and, alternative mechanism for allocating limited resources to the most productive uses.

b) Intensive Management - Are there new, more efficient ways of fulfilling mission objectives which are outside the methods currently employed?

c) Productivity - Given the way we do business, are there ways of saving resources by having a better understanding of how budgeted funds are used and what outputs or services are obtained? Can this information be used to increase the productivity of the existing program?

d) Modernization and Maintenance - Are there opportunities to save future OM&R dollars by making state-of-the-art-investments at existing projects? Can the allocation of resources be improved by developing more thorough and comprehensive guidelines for determining the need, extent and timing of project expenditures associated with major maintenance and rehabilitation?

The study is scheduled for completion in September 1992.

FUTURE STRATEGY USING NEW DECISION SUPPORT TOOLS

USACE O&M managers must be focused on accomplishing their missions through making the best use of limited dollars for achieving maximum efficiency and effect on service. They must also be able to produce formal, explicit justifications to support judgement and experience.

Accomplishing this objective requires the creation of evaluation criteria and consistent measurement techniques. These new analytical procedures can be accomplished without adding unrealistic burdens to the administration of the annual budget process. One way to mold these new procedures into the process is through and tied to the Automated Budget System (ABS).

The ABS and budget matrix are accepted by USACE managers as a tool for budget formulation. Neither of these tools, however, make allocation decisions. The ABS simply records rank-ordered preferences made by O&M personnel.

Additions are needed to the ABS to help decision makers rank order O&M work elements for the future.

APPROACH

One approach being pursued at this time is incremental analysis coupled with CIs. Incremental analysis seeks ways to estimate the economic value of competing maintenance dollars (i.e., a dollars worth of maintenance equals X dollars of service rendered for Y project or purpose) without overtaxing the resources of the USACE and improves and supports rather than replaces professional judgement. Incremental analysis draws on professional judgements in establishing a link between CIs and service quality, making it possible to weight alternative investments in maintenance and repair in terms of purchased CI improvements.

CIs are limited in their use as a measurement tool to compare structures that do not produce equivalent services. Rational choices in these cases requires consideration of the impact of maintenance/repair procedures on the quality of services provided. Figure 1 shows the expected deterioration of a facility over time. Major repairs shift the curve up and to the right. Of interest to decision makers is the shape of this relative curve, representing the expected value of the level of services provided by a structure over its lifetime. The shape of this service curve is unknown, as is the location of the CI value for a particular facility, but the best available clues exist in the experience of professionals intimately acquainted with the operations of particular facilities. CIs must therefore be converted to relevant measures of the services provided and include considerations of changes in economic benefits. In other words, there must be a cost/benefit measure to compare competing investments when the services provided are different in kind.

Research underway, in the IOMT program, has created a new procedure called QUADRANT as a means of linking the measurement of service quality and changing economic benefits with maintenance CI and the ABS. These four entities form the four corners of this new analytical procedure.

In the absence of historical records that link maintenance activities to economic benefits, QUADRANT uses the judgements of experts to predict impacts of activities on the quality of service provided. QUADRANT has three linked steps or three levels of complexity for structuring maintenance policy decisions. Level One and Two produce measures of the cost-effectiveness of a maintenance procedure. In Level One, alternatives are compared in terms of reductions in the probability that service will fall below some minimum standard. In Level Two, analysis compares the expected levels of service

following alternative repairs. Drawing on available data, Level Three produces a cost-benefit measure for comparing unlike projects. The overall method can be introduced level by level over time, building on accumulated experience.

This procedure is still in the developmental stages, but has been presented to different groups over the past year. Most have indicated their willingness to participate in the next phase of the research - that of data collection at specific project sites to test the practical application of QUADRANT. A more detailed discussion of incremental analysis can be found in Attachment 1.

One corner of the QUADRANT model is proceeding along nicely, i.e., CIs. It is our intention that CIs will become a part of the budget submission for FY 94. For those elements that have basically completed CI forms or procedures, CIs will be generated and submitted in the ABS along with the budgetary data for FY 94. Table 1 list the test sites where CI activities have been conducted.

While we recognize that CIs are not perfect or absolutes, they are a means to help us make better and more informed decisions. It is planned that for FY 95 and beyond, CIs coupled with QUADRANT and/or other decision support tools will be used extensively in the decision making process. The procedures for submitting CIs in the ABS will be forthcoming.

It is anticipated that a QUADRANT type procedure will allow for the rank-ordering of most alternative maintenance policies; however, when rehabilitation enters the picture and more complex decisions are required, additional procedures will be needed. Reliability indices will then come into play.

Reliability focuses on the probability of a structural component's unsatisfactory performance and whether this is likely to increase in time, whereas CIs provide an overall reference tool for a facility providing the opportunity to establish goals for minimum allowable condition levels. The calculation of reliability is a time consuming and resource intensive process. For this reason, reliability analyses will be limited to rehabilitation and/or modernization reports. These more costly maintenance projects require a more in-depth procedure for making decisions.

The Options Study will hopefully produce additional policies and procedures that can be used in the budget arena to provide and/or improve our decision making process. It could alter the above ongoing approaches by refining or replacing these procedures. Nonetheless, we must move on.

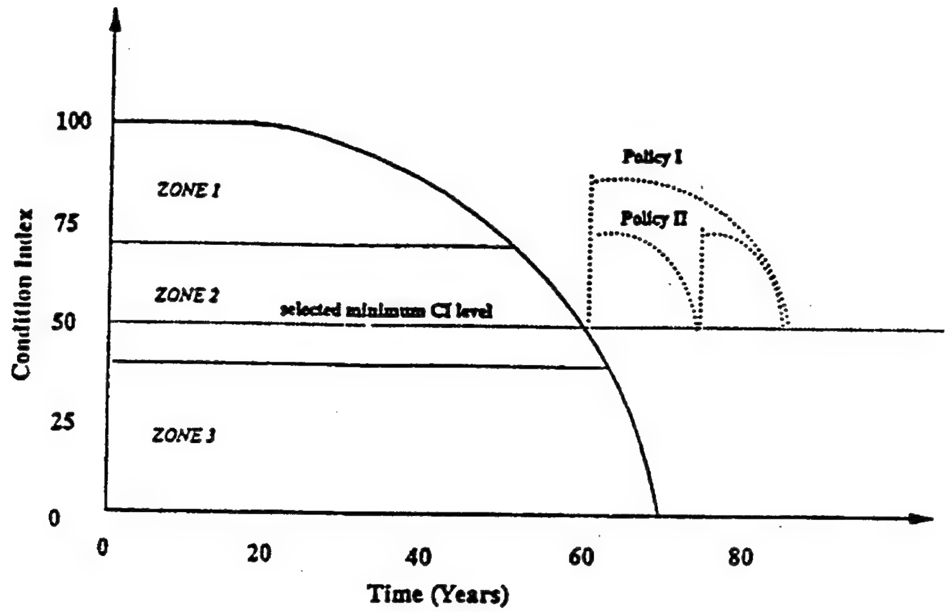

FIGURE 1

EXAMPLE OF CONDITION INDEX MAINTENANCE POLICY ANALYSIS

TABLE 1

CONDITION INDEX TEST SITES

DISTRICT	WATERWAY	PROJECT	COMPONENT EVALUATED
Rock Island	Mississippi River	Lock & Dam 15	CLW,MG,SSP
	Mississippi River	Lock & Dam 19	CLW,MG,SSP
	Mississippi River	Lock & Dam 20	CLW,MG,SSP
	Illinois River	Peoria Lock & Dam	CLW,MG,SSP
	Illinois River	LaGrange Lock & Dam	CLW,MG,SSP
	Illinois River	Lockport Lock & Dam	CLW,MG,SSP
	Chicago River	Chicago Lock	CLW,MG,SSP
	Calumet River	T.J.O'Brien Lock	CLW,MG,SSP
Detroit	Lake Michigan	Muskegon Harbor	BW,JT
Pittsburgh	Ohio River	Dashield Lock & Dam	CLW,MG,SSP
Nashville	Tennessee River	Wilson Lock & Dam	CLW,MG,SSP
	Tennessee River	Kentucky Lock & Dam	CLW,MG,SSP
	Tennessee River	Guntersville Lock & Dam	CLW,MG,SSP
	Cumberland River	Barkley Lock & Dam	CLW,MG,SSP
	Cumberland River	Old Hickory Lock & Dam	CLW,MG,SSP
	Cumberland River	Fort Louden Lock & Dam	CLW,MG,SSP
	Cumberland River	Melton Hill Lock & Dam	CLW,MG,SSP
New Orleans	Intercoastal Waterway	Port Allen Lock	CLW,MG,SSP
Tulsa	Arkansas River	Chouteau Lock & Dam 17	CLW,MG,SSP
		Newt Grahm Lock & Dam 18	CLW,MG,SSP
Portland	Columbia River	John Day Lock & Dam	CLW,MG,TD
		The Dalles Lock & Dam	CLW,MG,TD
San Francisco	Pacific Ocean	Santa Cruz Harbor	BW,JT
		Moss Landing Harbor	BW,JT
		Monterey Harbor	BW,JT

CLW - CONCRETE LOCKWALLS
BW - BREAKWATERS
MG - MITER GATES
JT - JETTIES
SSP - STEEL SHEET PILES
TD - TIMBER TRAINING DIKES

ATTACHMENT 1

INCREMENTAL ANALYSIS METHODOLOGY FOR PRIORITIZING O&M PROJECTS

Development of any analytical model for a complex decision-making process is not a simple undertaking; especially if this model is going to be used at various levels in the decision-making process.

Past practices of the USACE have concentrated on routine preventive maintenance which can result in unnecessary maintenance and the inappropriate expenditure of resources.

Predictive maintenance management is becoming more and more accepted as a cost effective alternative to the more traditional method of performing preventive maintenance. Predictive maintenance policies depend fundamentally on monitoring the condition and performance of operating systems. Or maintenance investments are linked directly to observed changes in the condition of a facility. From an economic perspective, the critical point in time occurs when the marginal damages to society that result from deferring a maintenance investment exceed the marginal costs of performing the maintenance activity.

Incremental maintenance analysis implies that maintenance spending as incremental investments in an existing project produces a measurable return in project benefits. Comparison of these estimated costs and returns provide a rational basis for making justified decisions. Analysis of a proposed maintenance policy, then, depends on the establishment of a link between the investment and observed changes in the services provided to users or customers of the project.

Important advantages of linking incremental maintenance analysis to predictive maintenance are the potential for basing investment decisions on empirical evidence, and the existing support for predictive maintenance in the USACE. An important disadvantage is that predictive maintenance is information-intensive.

DEFINING THE INCREMENTAL ANALYSIS APPROACH

The goal of this research is to create an operational system of predictive maintenance planning that supports and extends professional judgements at the initiating levels, while allowing for replication of rankings and for their comparisons at higher decision levels. To achieve this goal requires the linking of maintenance actions to predicted service delivered. The approach being taken will initially be driven by codifying and formalizing engineering judgements, but in the long run, will be empirically

tested and refined as CI data are extended over time and across facilities.

REMR activities are best understood as efforts to interrupt or delay the gradual process of structural deterioration. REMR activities are also purchases in the reduction in the probability that the quality of service at a project will decline to some designed level. Consequently, the method being developed will estimate the change in quality of service that is expected to result from each REMR activity and translate that change into a monetary estimate of benefits to the user.

BUILDING THE MODEL

The logic of analyzing a predictive maintenance investment is represented by Figure 2-1.

Steps 1 and 2 depend on the existence of reliable indicators of the condition of a project before and after a maintenance activity; hence CIs.

Step 3 requires measures of service provided before and after maintenance as related to its condition. This, obviously, is the most challenging of this approach. Until a historical record accumulates linking maintenance investments to observed changes in CI, the actual levels of service following a maintenance investment will be unknown. In the interim, relevant probabilities will have to be assessed subjectively by questioning O&M experts and producing probability density functions for levels of service connected to particular levels of a facility CI.

Step 4 depends on the availability of data relating changes in service quality to costs avoided by project clients or users.

DEVELOPING THE MODEL

A complex decision is broken down into its evaluative and predictive components. Choices that are controlled by a decision maker (choice of a maintenance action) are distinguished from events that are determined by chance (length of time required to move a tow through a lock). The probabilistic structure of a maintenance decision at a lock is shown in Figure 2-2. Each branch of the decision fork represents an alternative maintenance action that the decision maker may choose. In each event, the decision maker is uncertain of the effect that a particular action will have on the performance of the lock chamber. The uncertainty of the maintenance outcomes is represented by the branches of the chance forks. The logical choice depends on the relative desirability of achieving one level of service or

another and the likelihood that a particular outcome will result from that maintenance action. Or as in Step 3 above, the decision maker is called on to assess the likelihood that a given level of service will occur given the level of CI attained by the maintenance action.

SUMMARY

This decision analysis approach depends fundamentally on the quality of professional judgement. Current theoretical and applied literature suggests that no satisfactory means existing for establishing the connection between condition and service at the present time other than professional judgement. At some point in the future, once sufficient data has been collected from CI inspections, this link can be established empirically.

While relying significantly on professional judgement, incremental analysis reduces subjectivity by isolating economic impacts from non-economic factors that enter into rankling decisions and by reducing the guesswork in economic benefit estimation. A manager choosing not to prioritize on the basis of economic efficiency will be pressed to account for his decision. This is a significant step toward consistency that does not preclude decisions based on non-economic factors. Rather, it makes tradeoffs more explicit and subject to review.

The method proposed here is designed to improved on current practice by capturing expert judgements in a logical and systematic fashion. This approach reflects the conviction that decisions are best made by decision makers who have a full appreciation of both the complexity of problems and the available tools for solving them.

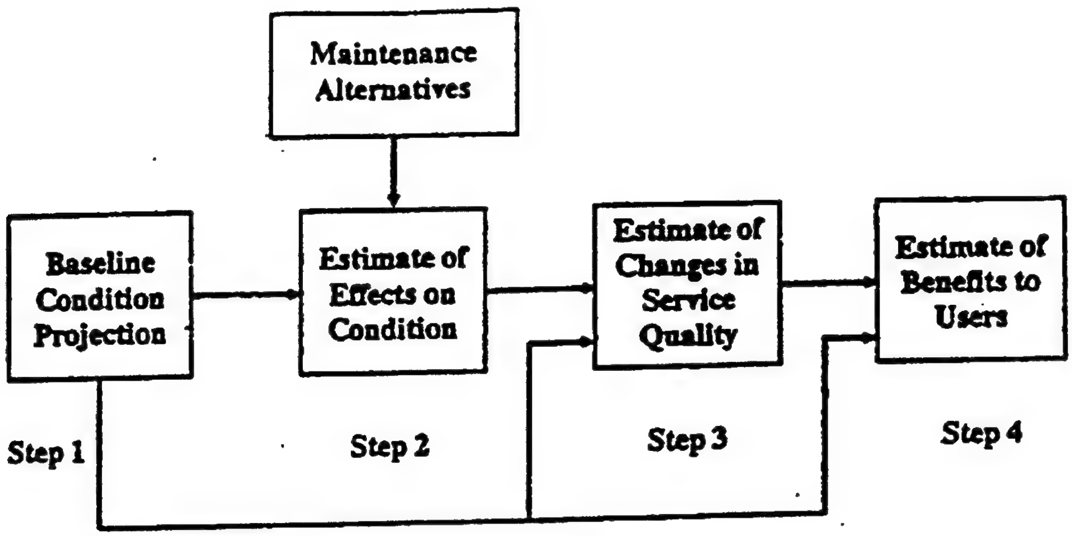

FIGURE 2-1

THE BASIC LOGIC OF INCREMENTAL ANALYSIS

1. The baseline condition and condition deterioration of Lock A are projected.

2. The effects of the proposed maintenance activity on the condition of Lock A are estimated.

3. These expected changes in the physical condition of Lock A are converted into expected changes in the services provided by Lock A.

4. The economic value of the expected changes in the services provided by Lock A is estimated.

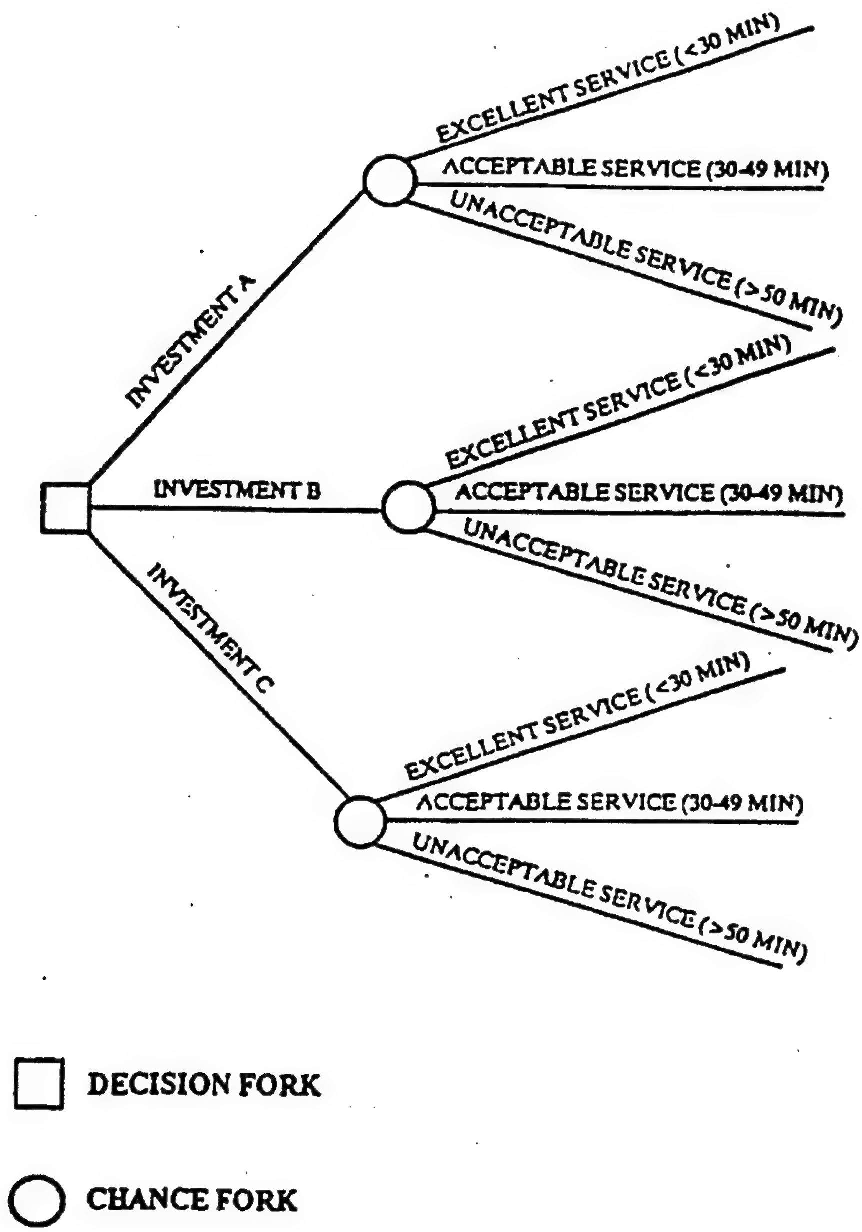

FIGURE 2-2

A DECISION-FLOW DIAGRAM FOR MAINTENANCE AT A NAVIGATION LOCK

Appendix I: CECW-O Memorandum on Implementation of CIs

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
WASHINGTON, D.C. 20314-1000

REPLY TO
ATTENTION OF:

19 Dec 91

CECW-O

MEMORANDUM FOR All Major Subordinate Commands

SUBJECT: Implementation of Condition Indices for the FY 94 Budget and Beyond

1. For the last five years, we have been developing procedures (through the Repair, Evaluation, Maintenance and Rehabilitation Program) for evaluating the physical condition of a piece of equipment or a structure using visual observations and measurements.

2. As an organization, we need to begin to apply these procedures on a yearly basis to judge the capability of our facilities to meet service expectations and to gauge physical deterioration. Without utilization of this tool and others being developed, we will continue to find it difficult to justify the need for rehabilitation and major maintenance, as well as to establish priorities for the use of our limited resources.

3. Beginning with the FY 94 budget submittal, Condition Indices (CI's) will become a routine submittal requirement. I realize we are a long way from perfection in the development of CI's, but we must move forward if we are to eventually realize the gains necessary to justify our resource requirements to higher authority.

4. The enclosed paper explains the procedures for submitting CI's with the project data in the FY 94 budget.

Encl

JOHN P. ELMORE, P.E.
Chief, Operations, Construction
and Readiness Division
Directorate of Civil Works

FY 1994 Guidance for the Inclusion of Condition Indices in the Civil Works Operation and Maintenance Automated Budget System (ABS)

1. The ABS system will be modified for the FY 1994 budget submittal to accommodate information about condition indices. The modification will entail a new requirement for districts to enter an output measure for work function records with the following category and feature cost codes:

N03	22.1	Lock and Salt Water Control Structure Maintenance
H03	23.1	Scheduled Power Plant Maintenance
H02	23.2	Non-Scheduled Power Plant Maintenance
H04	23.3	Comprehensive Replacement of Power Plant Generation Support Equipment and Facilities
N04	26.1	Breakwater, Jetty and Seawall Maintenance

The output measure is a 6 integer field that is presently a required entry for certain operations work function budget categories (e.g. real estate management, OSHA and engineering). Since condition indices affect maintenance budget categories only, there will be no overlap in the use of this data element among budget categories. The Budget EC will contain guidance limiting one structure per work function to avoid the possibility of having a work function covering more than one structure and thus having more than one condition index.

<u>The computer programs for ABS will require a nonzero entry for output measure for any of the category and feature cost codes listed above.</u>

2. For the FY 1995 budget submission and beyond, changes to the ABS system will include the creation of a project structure database and links between ABS and this new database:

a. Project Structure Database - this database will contain historical information on condition indices on every structure on every Corps maintained project. At a minimum it will contain the following information:

i) District Code

ii) Project CWIS Number

iii) Facility Identifier - two digit number identifying the individual structure within the project.

iv) Facility Description - a short description of the structure.

v) Condition Index for the Facility.

vi) Structure Identifier - four digit number identifying

the individual structure within the facility.

vii) Structure Code - a two character code identifying the type of structure (e.g. LG - lock gate). This would be useful in summarizing information about certain structures within the project and in relating the structure to a specific condition index.

viii) Structure Description - a short description of the structure.

ix) Date of Inspection - date of inspection in which condition index for structure was determined.

x) Condition Index - condition index determined for structure.

b. Link to ABS will be made by requiring an entry on each maintenance work function record for the Backlog of Maintenance and Repair (BMAR) Identifier. Below is a possible code structure that could be used:

1) First two digits - fiscal year that maintenance work function for structure first showed up for project. This would be needed only if you wish to keep track of maintenance on the structure over a period of time or how long the maintenance is deferred. There are problems in tracking maintenance work functions because districts can delete, add or break up maintenance work functions each year.

2) Second two digits - facility identifier on project (e.g., 78 - Lock and Dam 26).

3) Last two digits - structure identifer within facility (e.g., 01 - Lock Gate on Lock and Dam 26).

David Harmon
Computer Systems Analyst

Appendix J: Phone Survey for District Usage of Condition Indexes

District Survey of REMR CI Usage - Summary Page (3/97)

Districts Surveyed	Chief of Op/ConOp Aware That:		CI Systems In Use (or Have Tried)		Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
	CI's Exist	District Use of Them	Type	As Designed			
34	Y:12 (35%)	Y: 8 (24%)	-Coastal: 13	4	See Below	See Below	See Below
			-Lock Gates 13	6			
	N:14 (41%)	N:19 (56%)	-Lock Walls 10	5			
			-Hydropower 5	3			
	?: 8 (24%)	?: 7 (20%)	-Valves 4	2			
			-Dike/Revet. 2	1			
			-Tainter Gate 2	--			

(cwperf/dist-srv.sum)

Districts that use or have tried at least one system: 23 (68%)

Districts that use or tried a system according to the specified procedures: 13 (38%)

Major Likes
1. Provides systematic approach for assessing structures.
2. Establishes a baseline for comparison of structural condition.
3. Guides imspectors to take a more detailed and thoughtful look at structures.
4. Helps in prioritizing repair projects.
5. Helps in documenting defects and repair needs.
6. Provides some improved methods over what was used previously.

Major Dislikes
1. Takes too much time, $, and people to do (nearly universal response).
2. Procedures don't provide information that couldn't be obtained otherwise.

Why Systems are Not Used
1. Takes too much time, $, and people to do (nearly universal response).
2. Lack of organizational awareness that REMR assessment procedures exist.
3. Lack of trained people who know the procedures.
4. Didn't think they were useful.

District Survey of REMR CI Usage (3/97)							
District No.	Chief of Op/ConOP Aware That:		CI Systems in Use (or Have Tried)		Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
	CI's Exist	District Use of Them	Type	As Designed			
1	N	N	-Coastal (by Eng.)	?			
2							(Not Contacted)
3	N	N	-Coastal (with Eng.)	Y		-(coastal) How Ebb Shoal is handled.	Lack of Awareness
4	Y	N	-Concr. LW - Miter Gate -Coastal	N N N	-systematic approach.		(Inl. Water. Sys. Appears to be misunderstood)
5	N	N					Eng. Does their structure eval. Didn't know what Eng. did.
6	N	N	-Coastal -Lock Gate	N	-tracking repairs.	CI's don't match District priorities.	–
7	?	?	-Coastal -Hydropower	Y &N N	-technically sound. -good basis for comparing structures.	Think systems not needed. OK what they already do.	Not enough time and $.
8							(Not Contacted)
9	Y	Y	None	–	–	–	-Too much time and $. -Could get same information otherwise.
10							(Not Contacted)
11	N	N	-Lock Gates (when dewatered) -Coastal (by Eng.)	N N	–	–	–

District Survey of REMR CI Usage (3/97)

District No.	Chief of Op/ConOP Aware That:		CI Systems in Use (or Have Tried)		Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
	CI's Exist	District Use of Them	Type	As Designed			
12	N	N	-Hydropower	Y	-Helps prioritize work. -Gets people to focus on what needs to be done. -Like numeric rating.	-Hydropower needs software to make CI calc. easier.	–
13	?	?	-Dike/Revet. -Lockwall -Lock Gates	Y N N	-gives basis for comparison. -helps with bank stabiliz. decisions. -helps prioritize projects.	Time consuming.	Time Consuming.
14	N	N	-Coastal (structural part, but not functional part)	N (Struct. only)	-coastal structural -systematic approach.	-Functional tables too long.	
15	N	N	None	–	–	–	–
16	Y	Y	None	–	–	–	-No applicable structures in their District.
17	N	N	–	–	–	–	–
18	?	?	-Miter Gates -Lockwall -Valves	Y Y Y	-Good baseline for comparison. -Good inspection information. -Can lengthen time between dewatering.	–	–
19	Y	Y	None	–	-Coastal has some useful parts.	–	(Will try Coastal when budget submittals are needed).

District Survey of REMR CI Usage (3/97)							
	Chief of Op/ConOP Aware That:		CI Systems in Use (or Have Tried)				
District No.	CI's Exist	District Use of Them	Type	As Designed	Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
20	N	N	-Coastal (by Eng.)	N	–	-No way to retrain people. -Software. -Needs too much time, resources.	-Too much time and $. -Not enough people trained.
21	Y	Some	-Coastal -Miter Gate	Y Y	-Helps confirm condition and document defects.	-SI (Coastal) too subjective. -FI (Coastal) even more subjective. -Doesn't help get repair $.	–
22	?	?	None	–	–	–	-Eng. does most assessments. -Waiting for mandate to use CI to come down Eng. Chain.
23	?	N	-Hydropower	Y	-Some procedures are useful.	–	-Procedures not objective enough.
24	N	N	-Coastal (by Eng.)	Y	-Systematic approach.	–	–
25	N	N	–	–	–	–	–
26	?	?	None	–	–	–	Too much time and $ required.
27	N	N	-Lock Gates -Lock Walls -Coastal -Hydropower	N N N -Sometimes	-Systematic approach. -Consistency of inspections. -Coastal structural used a lot.	-Too much time and $. -Coastal functional too subjective.	–
28	Y	Y	-Lock Walls -Lock Gates	Y Y	-Forces a close look at structures.	Too much resources, monpower.	–
29	Y	N	-Lock Gates -Lock Walls -Valves -Dike/Revet.	N N N	–	-No performance criteria.	Too much time and $.

District Survey of REMR CI Usage (3/97)

District No.	Chief of Op/ConOP Aware That: CI's Exist	District Use of Them	CI Systems in Use (or Have Tried) Type	As Designed	Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
30	Y	Y	-Lock Walls -Lock Gates	Y Y	-Helps prioritize budget.	Too much resources, monpower.	–
31	?	?	None		–	–	Not sure they're useful.
32	N	N	-Coastal (with Eng.)	N	Structural eval.	Functional eval.	
33							(No response)
34	Y	N	-Hydropower -Lock Gates -Lock Walls -Valves -Tainter Gts. -Coastal	N Y N	Tainter Gate: gave them a better inspection method than had before.	-Hydropower-time intensive	too much time and $
35	?	?	Tainter Gate (tried once)	N	–	Needs too much time, people, equip.	Needs too much time, people, equipment.
36	Y	Y	-Lock Walls -Lock Gates	Y Y	-Forces close look at structures. -Allows good comparisons. -Allows good documentation of repair needs.		
37	Y	Y	-Lock Walls -Lock Gates -Valves	N	Some ideas of systems, which have been adopted.		Good in theory, but not in practice. Hydropower: too much time and $
38	Y	N	None Yet	–	–	–	–

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Appendix K: CI/Quadrant Technology Infusion Dilemma

Problem: CIs and Quadrant were originally marketed as tools to assist districts in making maintenance budget decisions. Neither system is being used in the budget process as originally intended. Several Districts were contacted and asked for their rationale for utilization/nonutilization of the CI/Quadrant tools. The following bullets are the major reasons for the nonutilization.

- CI inspections are perceived to be cost prohibitive.
- Districts believe that CI and/or Quadrant information is not critical to their prioritization of District maintenance activities
- The use of CIs/Quadrant has no impact on O&M funding for a District.

Solution: Civil Works O&M needs to reassess the best way to take advantage of the information that CI and Quadrant systems provide. The systems can support budget and engineering decisions at all levels including project, District, Division, and HQ. Some issues that need to be considered include.

- CIs and Quadrant can be effective tools for marketing/defending maintenance budget requirements to Corps Leaders, Assistant Secretary of the Army for Civil Works (ASACW), Office of Management and Budget (OMB), and Congress.
- The current focus of the CI/Quadrant benefits are perceived to be at the District. We need to change and emphasize that the CI/Quadrant systems support decisions at all levels including project, District, Division, and HQ.
- The nonbudget reasons for using CIs should also be marketed. CIs can help project personnel and District engineers understand the underlying basis for the condition and function of the structures. CIs provide good baseline information. CIs also are an objective procedure for assessing condition change over time.

Potential actions that will enhance utilization of the CI/Quadrant tools within CW:

1. Include CIs and Quadrant as part of funded inspections in ABS (and/or)
2. Include CIs as a part of the Periodic Inspection cycle
3. Market the local benefit of using CIs

- Case histories
- Reproducible baseline data
- Means of assessing event damage and degradation over time

4. Corporate utilization of CIs in O&M budget process
   - Make CIs an active component of corporate level O&M budget decisions and strategy.
     - Distribution of O&M funds
     - Quantifies impact of Funding short-fall
     - Corporate assessment of infrastructure health and changes in infrastructure health versus different levels of maintenance funding
   - Quality assurance of field generated CI data.
5. Corporate utilization of Quadrant to persuade ASACW and Congress that increased maintenance funding produces a measurable increase in user benefits.

Appendix L: O&M Top 10 Plus 1

Point Paper for Director of Civil Works

Most Important Things To Do in Managing the O&M Program Through 2005 (MSC & HQ Operations Chiefs' Top Ten plus 1)

Objective. Our goal is to demonstrate our ability to manage the O&M program efficiently and effectively. We are committed to an accurate accounting of O&M expenditures across all functional areas. We must present credible budgets that are linked to justified, consistent levels of service. We must better identify and prioritize O&M work. We should use risk-based tools to identify and prioritize operation and maintenance work, to help preserve an aging infrastructure.

1. **Cost savings initiatives, past and future.** The O&M cost savings initiative (Tisdale) report was released in August 1997. MSC's will continue to identify the cost savings initiatives that have been implemented or planned in response to the report. The cost savings will be documented Corps-wide at all projects and we will continue to look for future cost savings opportunities. **Action: MSC's relook initiatives and provide feedback ASAP. Timeline: 60 Days**

2. **Reaffirm definitions applicable to O&M budget and ensure consistent application.** Many budgetary terms are not sufficiently defined to ensure consistent cost accounting. These include backlog, on-site and off-site costs, direct and indirect costs, operations charges, and maintenance charges. Different interpretations of such terms leads to inconsistent cost accounting and lack of uniformity for compiling data from which to manage. **Action: HQ Operations Division, PM Division, and RM Directorate. Timeline: 45 Days**

3. **Fully implement the O&M Business Information Link (OMBIL).** Full implementation will allow us to capture business performance information for improved strategic management. OMBIL will provide everyone with access to nationally consistent information on outputs, cost and performance of the O&M business areas, thereby enhancing the management of service levels and goal prioritization. **Action: HQ Operations conduct OMBIL Roadshow with MSCs and Districts. Timeline: Complete roadshow in 90 Days. Field OMBIL IAW approved implementation schedule.**

4. **Define justified levels of service for all business functions.** Each MSC will establish standard levels of service for operational elements (e.g. roads, campsites, restrooms, mowing, etc.) within all business functions. The levels of service will be based upon national factors such as level of use, cost effectiveness, customer expectations, etc. Performance measures should continue to be tied to budget priorities. Performance measures should be expanded for all business functions, along with benchmarks, at the national level. Ensure that the measures evaluate outputs generated by O&M expenditures. Command attention is essential. Full implementation of the performance measure process will aid in better defining justified levels of service. **Action: HQ, MSC and District Tiger Team for each O&M business function. Timeline: Complete national (broadband) standards in 6 months. Complete MSC regional adjustments within 9 months (3 months beyond national standards).**

5. **Inaccurate field cost accounting impacts budget versus expenditure analysis.** Accurate accounting of expenditures is essential to reflect true costs. Proper accounting is needed to make sure that cost reduction efforts are managed correctly. Education and guidance at all levels is needed to ensure proper costs are reflected in expenditure reports. Inaccurate data precludes our ability to monitor changes in the cost of doing business. **Action: DCW reiterates need for accounting "excellence" to assure consistency of financial data across MSCs. Timeline: Operations Division prepares Memo for DCW signature within 7 days.**

6. **Validate effectiveness of offsite costs.** The value-added of district office activities to providing O&M services needs to be assured. O&M managers should be allowed to buy support services from the most economical, effective and responsive source (parent district, sister district, regional office or contract). This approach forces support functions to look at their business process and become more competitive. They should feel the same pressures for limited resources as the O&M community. This also ties in with upcoming district restructuring initiatives. **Action: MSC DETs, PMs, RMs and Commanders need to dialogue about offsite costs as part of RMB / Regional Business Center Process. Timeline: Start dialogue at next RMB / RBC meeting. Continue dialogue to assure offsite cost-effectiveness.**

7. **Develop tools to uniformly set priorities nationwide for maintenance needs.** The Corps has historically set funding priorities in a manner that factors in critical public interest factors, costs, and the need for the maintenance. However, there is currently no structured method, with repeatable results, for establishing these funding priorities. A potential method includes simplified existing

tools that the Corps has developed (Condition Indices, master planning, Quadrant, Activity-Based Costing, etc), integrated with assessments of the risks associated with not doing the maintenance, and the public interest in conducting the work. This method must be an easily used, quantifiable tool that can be used nationwide, providing uniform results. Other potential tools to aid in structured approaches to maintenance management include the Facilities and Equipment Maintenance (FEM) system and other inventory management systems. **Action: HQ Operations collaborates on development of simplified risk-based tools in conjunction with CPW. Timeline: 120-180 days.**

8. **Regionalize where beneficial.** The regionalization of selected O&M funded activities should be thoroughly explored and implemented where it will result in efficiencies and a better business process that is still responsive to the customer. A case in point is the transfer of one Division's regional role in hydropower to a district office that is collocated with the Power Marketing Agency. Another example is the regionalization of water management activities to eliminate duplicate overhead and functional positions. Other opportunities might include having one district provide GIS technology for shoreline management or forestry management plans for the entire region. **Action: MSC Commanders and RBC / RMB members. Timeline: Continuous dialogue through Regional Business Center leadership meetings.**

9. **Challenge inspection levels and inefficient requirements.** In February 1998, HQUSACE initiated a review to identify areas where inspection levels and regulatory requirements could be reduced or eliminated with little additional risk. Some of the activities include real estate utilization inspections, comprehensive Periodic Inspections of project structures, annual pesticide reports, etc. Reduced requirements can decrease both off-site and on-site costs. **Action: HQ Operations, Engineering and Real Estate Process Action Team reviews MSC recommendations for inspection level and frequency changes. Establish risk-based inspection criteria. Timeline: 120-180 days.**

10. **Address unfunded mandates challenges.** Many unfunded mandates (e.g., analysis of critical structural steel members, inspection of drainage pipes, expanded bridge inspections, and EPA's new PCB "mega-rule") are oftentimes performed at the expense of other O&M work. Future unfunded mandate requirements should be highlighted using the RMB process and in other forums to emphasize the added burden to the Corp's leadership and to give them an opportunity to strategize for alternative funding sources for these new requirements. OMB and Congress need to be informed of the impacts of externally driven unfunded mandates as well. **Action: MSCs and HQs identify "hit-list" of most egregious unfunded mandates. MSCs should discuss at RMB / RBC**

meetings. HQ PM Division should educate committees on impacts of externally driven unfunded mandates. Timeline: Continuous.

Celebrate and Share Small-Scale Grass Roots Initiatives. Local Districts and Project Offices are using, on a daily basis, a wide variety of innovative tools and techniques to overcome budget constraints. For example, partnering with the Federal Prison at Greenville, Illinois, Carlyle Lake generated over $100,000 in cost avoidance by using prison labor on unfunded backlog maintenance work. Re-employing a team member on worker's compensation in a different position resulted in actual productive work of $50,000 rather than the employee not working, but being paid the same amount. The St. Louis District at the Rivers Project Office entered into a Challenge Cost Share Agreement with the Rivers Foundation in the amount of $3.2 million for the National Great Rivers Museum (Visitor Center) exhibition. Using the preventative maintenance approach, staff at Clarence Cannon Dam tested turbine oil quality by sampling in lieu of standard periodic oil changes, saving $10,000/annually. Innovative thinking by the Mountain Home Hydropower Branch of the Little Rock District shortened a typical 75-day outage down to 10 days through a creative approach to generator rotor field pole replacement. This practice could translate into as much as $1.3 million in added generation, not to mention the improvements in availability and standby reserve. These examples typify the creative thinking that field personnel are using to get the job done and leverage constrained resources. **Action: MSC Commanders identify, celebrate and share small-scale initiatives throughout the Corps at BOD or through other avenues to demonstrate that every small-scale saving adds to overall O&M effectiveness. Timeline: Continuous.**

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14. ABSTRACT

A Condition Index (CI) is a snapshot look at the physical condition of a structure or structure component. CIs for Civil Works infrastructure were developed at the direction of the Civil Works Directorate Headquarters, U.S. Army Corps of Engineers as part of the Operations Management Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation research program to assist in the prioritization and justification of the operations and management (O&M) budget. This working document describes how CIs were developed, what they were intended to accomplish, current and potential benefits from using CIs, and current policy relative to CI utilization.

The O&M Management Tools program, scheduled for funding in FY00-02, allows this opportunity to reassess CIs and ensure they both meet their original and modified design intent and are sufficiently user friendly to assure technology transfer and utilization.

15. SUBJECT TERMS
condition index (CI)
infrastructure
operation and maintenance (O&M)
O&M Management Tools Program
civil works programs

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